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Best Demonstrated Available Technology (BDAT) Background Document for Cyanide Wastes

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BEST DEMONSTRATED AVAILABLE TECHNOLOGY (BDAT) BACKGROUND DOCUMENT FOR CYANIDE WASTES

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We greatly appreciate the cooperation of the individual companies that permitted their plants to be sampled and that submitted detailed information to the U.S. EPA on treatment of these wastes.

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1. INTRODUCTION

Pursuant to section 3004(m) of the Resource Conservation and Recovery Act (RCRA), enacted as a part of the Hazardous and Solid Waste Amendments (HSWA) on November 8, 1984, the Environmental Protection Agency (EPA) is promulgating treatment standards based on best demonstrated available technology (BDAT) for the cyanide-containing electroplating and metal heat treating wastes identified in 40 CFR 261.31 as F006, F007, F008, F009, F010, F011, and F012 and for the commercial chemical product wastes identified in 40 CFR 261.33 as P013, P021, P029, P030, P063, P074, P098, P099, P104, P106, and P121. The Agency previously established treatment standards for metals in F006 nonwastewaters with the First Third listed hazardous wastes (53 FR 31137, August 17, 1988). The Agency reserved the nonwastewater cyanide treatment standard for F006 waste. Today, the Agency is promulgating amenable and total cyanide treatment standards for F006 nonwastewaters. Also, the Agency is promulgating cyanide and metal standards for F007, F008, F009, F010, F011, F012 wastewaters and nonwastewaters. Compliance with the final BDAT treatment standards is a prerequisite for the placement of these wastes in units designated as land disposal units according to 40 CFR Part 268. The effective date of the treatment standards for F006 nonwastewaters and for F007, F008, and F009 wastes is July 8, 1989. The effective date of the treatment standards for F011 and F012 wastes is July 8, 1989, except that the cyanide standards for electroplating nonwastewaters (F007-F009) shall apply until December 8, 1989. The more rigorous cyanide standard

(110 mg/kg total cyanide and 9.1 mg/kg amenable cyanide) is effective December 8, 1989, for F011 and F012 nonwastewaters. The effective date of the treatment standards for F010, P013, P021, P029, P030, P063, P074, P098, P099, P104, P106, and P121 wastes is June 8, 1989.

This background document provides the Agency's technical support for selecting and developing proposed treatment standards for the constituents to be regulated for the electroplating and metal heat treating wastes. Sections 2 through 7 present information for the F-code wastes. Section 2 describes the industries affected by regulation of these wastes, explains the processes generating these wastes, and presents available waste characterization data. Section 3 specifies the applicable and demonstrated treatment technologies for these wastes and presents descriptions of those technologies. Section 4 contains performance data for the demonstrated technologies, and Section 5 analyzes these performance data to determine BDAT for each waste. Section 6 presents the rationale for selection of regulated constituents, and Section 7 presents the promulgated BDAT treatment standards for the regulated constituents. Section 8 discusses associated inorganic cyanide P-code wastes and details the development of the proposed treatment standards for these wastes.

EPA's promulgated methodology for developing BDAT treatment standards is described in two separate documents: Generic Quality Assurance Project Plan for Land Disposal Restrictions Program ("BDAT") (USEPA 1987) and the Methodology for Developing BDAT Treatment Standards (USEPA 1988d). The second document also discusses the petition process to be followed in requesting a variance from the BDAT treatment standards.

For the purpose of determining the applicability of the proposed treatment standards, wastewaters are defined as wastes containing less than 1 percent (weight basis) total suspended solids* and less than 1 percent (weight basis) total organic carbon (TOC). Waste not meeting this definition must comply with the proposed treatment standards for nonwastewaters.

Cyanide-containing wastes generated in metal finishing operations contain cyanide and BDAT list metals. The following paragraph details the promulgated BDAT for nonwastewaters and wastewaters for each waste. Table 1-1, at the end of this section, presents this information in tabular form. In the January 11, 1989, proposed rule, EPA defined three subcategories of cyanide wastes from the metal finishing industry: Metal Finishing Aqueous Liquids, Metal Finishing Organic Liquids, and Metal Finishing Sludges. The Agency has reexamined the need for categorizing these wastes into these subcategories and believes that they are unnecessary for the establishment of these treatment standards. Rather, the Agency has decided that presentation of the treatment standards on a waste code basis (according to the wastewater and nonwastewater forms of the waste) provides a sufficient distinction of the treatability groups. The revised treatment standards are promulgated based on the difference in the processes generating these wastes (e.g., electroplating, metal heat treating) rather than on the difference in physical form of the waste. Upon reexamination of the characteristics of the metal finishing cyanide wastes, the Agency believes that the process generating the wastes influences the treatability of the waste to a greater extent than the physical form of the waste, based on the variability in complexed cyanide, iron, and other metals concentrations among these metal finishing processes.

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* The term "total suspended solids" (TSS) clarifies EPA's previously used terminology of "total solids" and "filterable solids." Specifically, total suspended solids is measured by Method 209c (Total Suspended Solids Dried at 103 to 105°C) in Standard Methods for the Examination of Water and Wastewater, 16th Edition (APHA, AWWA, and WPCF 1985).

Alkaline chlorination is determined to be BDAT for cyanide in wastewaters for waste codes F007, F008, and F009, generated in electroplating operations. For BDAT list metals in F007, F008, and F009 wastes in wastewaters, BDAT is determined to be chemical precipitation followed by filtration. The Agency is not promulgating treatment standards for F006 wastewaters at this time. For cyanide in F006, F007, F008, and F009 nonwastewaters, BDAT treatment standards are based on generation of these wastes from an alkaline chlorination treatment system. For metals in F007, F008, and F009 nonwastewaters, stabilization is determined to be BDAT. Stabilization was the basis of the F006 nonwastewater BDAT treatment standards for metals, promulgated with the First Third land disposal restrictions.

For F011 and F012, generated in metal heat treating operations, BDAT for cyanide in wastewaters is determined to be alkaline chlorination.

For BDAT list metals for these waste codes in wastewaters, chemical precipitation followed by filtration is determined to be BDAT. For cyanide in F011 and F012 nonwastewaters, BDAT treatment standards are based on generation of the waste from a treatment system consisting of electrolytic oxidation followed by alkaline chlorination. For metals in F011 and F012 nonwastewaters, stabilization is determined to be BDAT.

For cyanide in F010 wastes, incineration is determined to be BDAT for nonwastewaters. Alkaline chlorination is determined to be BDAT for F010 wastewaters, such as scrubber water produced in incineration treatment of these wastes. EPA expects that such scrubber waters would meet the BDAT treatment standards without treatment in a well-operated incineration system. EPA believes that F010 waste may exist as a bilayered waste (i.e., as an oil layer and a water layer) and the generator of this waste may choose to treat the aqueous layer of the waste separately by alkaline chlorination. The Agency would like to note that treatment residuals from treating F010 wastewaters are listed as the F012 waste code (wastewater treatment sludges from metal heat treating operations) and would thus be subject to the cyanide standards for F012 nonwastewaters. Such sludges would thus not be subject to the standards based on performance of incineration. Because the Agency believes that these aqueous F010 wastewaters have waste characteristics similar to those of F011 and F012 wastewaters, the Agency is transferring the performance of the treatment system of alkaline chlorination for cyanide. The Agency notes that if a generator or treater of an F010 waste does not separate the waste into the two layers, that facility would have to meet the 1.5 mg/kg treatment standard for total cyanide in the nonwastewater residuals (based on incineration).

The promulgated treatment standards for total and amenable cyanide for F007, F008, F009, F010, F011, and F012 wastewaters and F006, F007, F008, and F009 nonwastewaters were developed based on data on alkaline chlorination followed by chemical precipitation, filtration, and sludge dewatering that were received during the public comment period. These data, which were collected from treatment of mixed metal finishing wastewaters and sludges, were noticed for further public comment and are part of the Administrative Record for this rule.

The promulgated treatment standard for amenable cyanide for F011 and F012 nonwastewaters has been recalculated from the proposed rule from the same data upon which the proposed standard was based. The proposed standard was derived from an incorrect detection limit for amenable cyanide. Also, one of the percent recovery factors used to adjust these data for accuracy was reported in error in the proposed background document. The calculation of the revised standard is clarified in Appendix D.

For cyanide, the promulgated treatment standards reflect total waste concentration. The units for the total waste concentration are mg/kg (parts per million on a weight-by-weight basis) for nonwastewaters and mg/l (parts per million on a weight-by-volume basis) for wastewaters. For BDAT list metals in nonwastewaters, the promulgated treatment standards reflect the leachate concentration from the Toxicity Characteristic Leaching Procedure (TCLP). The units for the leachate concentration are mg/l. For BDAT list metals in wastewaters, the promulgated treatment standards reflect the total waste concentration, and the units are mg/l.

The promulgated treatment standards for the wastewater and nonwastewater forms of the metal finishing wastes are shown in Tables 1-2 through 1-5. The P-code cyanide-containing wastes for which standards are promulgated contain soluble cyanide salts. These wastes are expected to be similar in characteristics to the wastes generated in metal heat treating (specifically F011 and F012); thus, the treatment standards proposed for these wastes are also transferred to the P-code cyanide wastes. The promulgated treatment standards for the P-code cyanide wastes are presented in Table 1-6. Wastes that, as generated, contain the regulated constituents at concentrations that do not exceed the proposed treatment standards are not prohibited from land disposal units.

Treatment standards for the wastewater and nonwastewater forms of F019 have not been promulgated with the land disposal restrictions for Second Third scheduled wastes. This waste was originally scheduled for regulation in the First Third, with the statutory deadline of August 8, 1988. The Agency believes that F019 wastes are dissimilar to the electroplating and metal heat treating wastes because of the high concentration of iron complex cyanides in F019 wastes. The Agency believes that the source of the iron complex cyanides is the soluble ferrocyanide compounds (such as potassium ferrocyanide) that are used as constituents in aluminum conversion coating compounds or baths. Therefore, the only cyanides present in these conversion coating baths would be the iron complex cyanides that are used as a component of the coating. The Agency believes that F019 nonwastewaters or the wastewater treated to generate this waste have substantial concentrations of iron complex cyanides and cannot be treated by conventional oxidation-reduction processes upon which BDAT treatment standards for the other metal finishing wastes are based. Since the Agency did not promulgate standards for the wastewater and nonwastewater forms of F019, land disposal of these wastewaters and nonwastewaters will continue to be regulated by the "soft hammer" provisions in 40 CFR 268.8. EPA intends to promulgate numerical treatment standards for cyanide and metal constituents for F019 by May 8, 1990.

Table 1-1 Summary of Promulgated BDAT for Cyanide Wastes

Waste codes	Type of treatment residual	Technologies upon which BDAT treatment standards are based
F007, F008, F009, F011, F012	Wastewater	Alkaline chlorination, chemical precipitation, polishing filtration
F006 (cyanide), F007, F008, F009	Nonwastewater	Alkaline chlorination, chemical precipitation, sludge dewatering, stabilization
F011, F012	Nonwastewater	Electrolytic oxidation, alkaline chlorination, chemical precipitation, sludge dewatering, stabilization
F010	Wastewater	Alkaline chlorination
F010	Nonwastewater	Incineration

Table 1-2 BDAT Treatment Standards for F006

NONWASTEWATERS

	Maximum for any single grab sample	
Constituent	Total composition (mg/kg)	TCLP (mg/l)
Cyanide (total)	590	Not applicable
Cyanide (amenable)	30	Not applicable

Table 1-3 BDAT Treatment Standards for F007, F008, and F009

NONWASTEWATERS

Constituent	Maximum for any single grab sample Total composition (mg/kg)	TCLP (mg/l)
Cyanide (total)	590	Not applicable
Cyanide (amenable)	30	Not applicable
Cadmium	Not applicable	0.066
Chromium (total)	Not applicable	5.2
Lead	Not applicable	0.51
Nickel	Not applicable	0.32
Silver	Not applicable	0.072

WASTEWATERS

Constituent	Maximum for any single grab sample Total composition (mg/l)	TCLP (mg/l)
Cyanide (total)	1.9	Not applicable
Cyanide (amenable)	0.10	Not applicable
Chromium (total)	0.32	Not applicable
Lead	0.04	Not applicable
Nickel	0.44	Not applicable

Table 1-4 BDAT Treatment Standards for F010

NONWASTEWATERS

Constituent	Maximum for any single grab sample Total composition (mg/kg)	TCLP (mg/l)
Cyanide (total)	1.5	Not applicable

WASTEWATERS

Constituent	Maximum for any single grab sample Total composition (mg/l)	TCLP (mg/l)
Cyanide (total)	1.9	Not applicable
Cyanide (amenable)	0.10	Not applicable

Table 1-5 BDAT Treatment Standards for F011 and F012

NONWASTEWATERS

Constituent	Maximum for any single grab sample Total composition (mg/kg)	TCLP (mg/l)
Cyanide (total)	110	Not applicable
Cyanide (amenable)	9.1	Not applicable
Cadmium	Not applicable	0.066
Chromium (total)	Not applicable	5.2
Lead	Not applicable	0.51
Nickel	Not applicable	0.32
Silver	Not applicable	0.072

WASTEWATERS

Constituent	Maximum for any single grab sample Total composition (mg/l)	TCLP (mg/l)
Cyanide (total)	1.9	Not applicable
Cyanide (amenable)	0.10	Not applicable
Chromium (total)	0.32	Not applicable
Lead	0.04	Not applicable
Nickel	0.44	Not applicable

Table 1-6 BDAT Treatment Standards for P013, P021, P029, P030, P063, P074, P098, P099, P104, P106, and P121

NONWASTEWATERS

Constituent	Maximum for any single grab sample Total composition (mg/kg)	TCLP (mg/l)
Cyanide (total)	110	Not applicable
Cyanide (amenable)	9.1	Not applicable
Nickel (P074 only)	Not applicable	0.32
Silver (P099 and P104 only)	Not applicable	0.072

WASTEWATERS

Constituent	Maximum for any single grab sample Total composition (mg/l)	TCLP (mg/l)
Cyanide (total)	1.9	Not applicable
Cyanide (amenable)	0.10	Not applicable
Nickel (P074 only)	0.44	Not applicable

2. INDUSTRIES AFFECTED AND WASTE CHARACTERIZATION

According to the schedule shown in 40 CFR 268.10-11, the following wastes from electroplating, metal heat treating, and chemical conversion coating operations in the metal finishing industry, defined in 40 CFR 261.31, are subject to the land disposal restriction prohibitions of RCRA:

Electroplating Operations

F006: Wastewater treatment sludges from electroplating operations except for the following processes: (1) sulfuric acid anodizing of aluminum; (2) tin plating on carbon steel; (3) zinc plating (segregated basis) on carbon steel; (4) aluminum or zinc-aluminum plating on carbon steel; (5) cleaning/stripping associated with tin, zinc, and aluminum plating on carbon steel; and (6) chemical etching and milling of aluminum.

F007: Spent cyanide plating bath solutions from electroplating operations.

F008: Plating bath residues from the bottom of plating baths from electroplating operations where cyanides are used in the process.

F009: Spent stripping and cleaning bath solutions from electroplating operations where cyanides are used in the process.

Heat Treating Operations

F010: Quenching bath residues from oil baths from metal heat treating operations where cyanides are used in the process.

F011: Spent cyanide solutions from salt bath pot cleaning from metal heat treating operations.

F012: Quenching wastewater treatment sludges from metal heat treating operations where cyanides are used in the process.

Section 2.1 describes the industries affected by the land disposal restrictions for F006-F012, and Section 2.2 presents descriptions of the electroplating and heat treating processes generating these wastes.

Section 2.3 summarizes the available waste characterization data for these wastes.

2.1 Industries Affected

The listed wastes F007, F008, and F009 are generated from electroplating operations where cyanides are used in the process. The listed waste F006 is generated from electroplating operations and may contain cyanide. The listed wastes F010, F011, and F012 are generated from metal heat treating operations where cyanides are used in the process.

Electroplating operations consist of the following processes: (1) common and precious metals electroplating, except tin, zinc (segregated basis),* aluminum, and zinc-aluminum plating on carbon steel; (2) anodizing, except sulfuric acid anodizing of aluminum; (3) chemical etching and milling, except when performed on aluminum; and (4) cleaning and stripping, except when associated with tin, zinc, and aluminum plating on carbon steel.

Metal heat treating operations include tempering, carburizing, carbonitriding (cyaniding), nitriding, annealing, normalizing, austenizing, austempering, quenching, siliconizing, martempering, and malleabilizing.

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* Zinc plating (segregated basis) refers to noncyanidic zinc plating processes. For example, wastewater treatment sludges from zinc plating using baths formulated from zinc oxide and/or sodium hydroxide would be excluded from the listing, while sludges from baths formulated from zinc cyanide and/or sodium cyanide would not be excluded. Where both cyanidic and noncyanidic baths are used, the exclusion applies to sludges from the noncyanidic plating processes as long as they are segregated from sludges that result from cyanidic plating processes.

In the preamble to the Effluent Limitations Guidelines for the Metal Finishing Industry (48 FR 32482, July 15, 1983), the Agency identified 13,500 facilities in the metal finishing industry that use 46 electroplating and metal finishing unit operations (including electroplating, heat treating, and chemical conversion coating).

Users of electroplating and metal heat treating operations generally fall under Standard Industrial Classification (SIC) code series 3000, which comprises fabricated metal products except machinery and transportation equipment; machinery except electrical; electrical and electronic machinery, equipment, and supplies; transportation equipment; measuring, analyzing, and controlling instruments; and miscellaneous manufacturing industries.

2.2 Process Description

Presented in this section are descriptions of each of the four operations that EPA has included as electroplating operations: electroplating, anodizing, chemical etching and milling, and metal cleaning and stripping. Also provided is a description of the metal heat treating operations.

2.2.1 Electroplating

Electroplating is the application of a thin surface coating of one metal upon another by electrodeposition. This surface coating is applied to provide corrosion protection, wear or erosion resistance, or antifrictional characteristics, or for decorative purposes. The electroplating of common metals includes the processes in which ferrous or nonferrous base material is electroplated with the following metals or metal alloys:

copper, nickel, chromium, brass, bronze, zinc, tin, lead, cadmium, iron, aluminum, or combinations thereof. The alloy brass consists of copper and zinc; the alloy bronze consists of copper and tin. Precious metals electroplating includes the processes in which a ferrous or nonferrous base material is plated with gold, silver, palladium, platinum, rhodium, indium, ruthenium, iridium, osmium, or combinations thereof.

In electroplating, metal ions in acid, alkaline, or neutral solutions are reduced to the metal on negatively charged (cathodic) surfaces. The cathodic surfaces are the objects being plated. The metal ions in solution are usually replenished by the dissolution of metal from positively charged surfaces (anodes) or small pieces contained in inert wire or metal baskets. Replenishment by dissolving metal salts is also practiced, especially for chromium plating. In this case, an inert material must be selected for the anodes. Hundreds of different electroplating solutions have been adopted commercially, but only two or three types are used widely for a particular metal or alloy. For example, cyanide solutions are popular for copper, zinc, brass, cadmium, silver, and gold. However, noncyanide alkaline solutions containing pyrophosphate have come into use recently for zinc and copper. Acid sulfate solutions are also used for plating zinc, copper, tin, and nickel, especially for relatively simple shapes. Cadmium and zinc are sometimes electroplated from neutral or slightly acidic chloride solutions.

Electroplating baths contain metals, metal salts, acids, alkalies, and various bath control compounds. All of these materials contribute to the wastewater streams through dragout of bath solutions on the plated parts, through batch dumps, or through floor spills. The sludge from the bottom of plating baths also contains metals and metal salts. Table 2-1 outlines some typical electroplating bath chemical compositions.

2.2.2 Anodizing

Anodizing is an electrolytic oxidation process that converts the surface of the metal to an oxide. The oxide coatings formed in anodizing provide corrosion protection, decorative surfaces, a base for painting and other coating processes, and special electrical and mechanical properties. Aluminum is the most frequently anodized material, while some magnesium and stainless steel (electropolish) and limited amounts of zinc and titanium are also treated.

Most anodizing is carried out by the immersion of racked parts in tanks; however, some continuous anodizing is done on large coils of aluminum, in a manner similar to continuous electroplating. For aluminum parts, the formation of the oxide occurs when the parts are made anodic in dilute sulfuric acid or dilute chromic acid solutions. The oxide layer begins formation at the outer surface of the base metal, and as the reaction proceeds, the oxide grows into the metal. The oxide formed last, known as the boundary layer, is located at the interface between the base metal and the oxide. The boundary is extremely thin and nonporous. Chromic acid anodic coatings are more protective than sulfuric acid coatings and have a relatively thick boundary layer.

Table 2-1 Chemical Compositions of Typical Electroplating Baths

Plating compound	Constituents	Concentration in bath (g/l)
Cadmium cyanide	Cadmium oxide	22.5
	Cadmium (as metal)	19.5
	Sodium cyanide	77.9
	Sodium hydroxide	14.2
Cadmium fluoborate	Cadmium fluoborate	251.2
	Cadmium (as metal)	94.4
	Ammonium fluoborate	59.9
	Boric acid	27.0
Chromium electroplate	Chromic acid	172.3
	Sulfate	1.3
	Fluoride	0.7
Copper cyanide	Copper cyanide	26.2
	Free sodium cyanide	5.6
	Sodium carbonate	37.4
	Rochelle salt	44.9
Gold cyanide	Gold (as potassium gold cyanide)	8
	Potassium cyanide	30
	Potassium carbonate	30
	Dipotassium phosphate	30
Acid nickel	Nickel sulfate	330
	Nickel chloride	45
	Boric acid	37
Silver cyanide	Silver cyanide	35.9
	Potassium cyanide	59.9
	Potassium carbonate (min.)	15.0
	Silver (as metal)	23.8
	Free cyanide	41.2
Zinc sulfate	Zinc sulfate	374.5
	Sodium sulfate	71.5
	Magnesium sulfate	59.9

Reference: USEPA 1980.

2.2.3 Chemical Etching and Milling

These processes are used to produce specific design configurations and tolerances or surface appearances on parts by controlled dissolution of the base metal with chemical etchants. Included in this classification are the processes of chemical milling, chemical etching, and bright dipping. Chemical etching is the same process as chemical milling, but the rates and depths of metal removal are usually much greater in chemical milling. Typical solutions for chemical milling and etching include solutions of ferric chloride, nitric acid, ammonium persulfate, chromic acid, cupric chloride, hydrochloric acid, and combinations of these etchants. Bright dipping is a specialized form of etching that is used to remove oxide and tarnish from ferrous and nonferrous materials and is frequently performed just prior to plating. Bright dipping solutions are usually composed of mixtures of two or more of the following acids: sulfuric, chromic, phosphoric, nitric, and hydrochloric.

2.2.4 Metal Cleaning and Stripping

Metal cleaning operations are designed to prepare metal surfaces for electroplating by removing oil, grease, dirt, and metal oxides, using water with or without a detergent or other dispersing agent. Cleaning can be done with alkaline (either electrolytically or nonelectrolytically), neutral, or acidic solutions. Nonelectrolytic cleaning, using both alkaline and acid solutions, can be done by either soak or spray methods. Acid cleaning can be referred to as pickling. Effective cleaning is also accomplished by alkaline electrolytic cleaning, or electrocleaning. Electrocleaning can be run cathodically (with the workpiece as the cathode), anodically (with the workpiece as the anode), or in periodic reversal (PR) mode, in which the current is periodically reversed from cathodic to anodic. Cleaning baths eventually become contaminated with metals derived from the cleaned parts.

Metal stripping is the chemical removal of metal plating coatings from base metal products by immersion of the plated part in an aqueous bath of appropriate chemical composition. When a plated coating on a part does not meet product quality specifications, it may be more economical to remove the metal plating and reuse the part than to scrap the entire plated part. Stripping baths can contain strong alkaline solutions of cyanide salts (to strip copper plating from steel parts, for instance) or strong acids. The stripping solution dissolves the plated coating, leaving the base metal essentially untouched.

2.2.5 Metal Heat Treating

Metal heat treating is the modification of the physical properties of a metal piece through the application of controlled heating and cooling cycles. Heat treating is most frequently accomplished by placing the metal parts in an atmosphere (air or other gases) at the appropriate temperatures for the appropriate period of time. Heat treating can also be accomplished by placing parts (usually small items) in molten salt baths, including baths using cyanide salts. After immersion in the salt bath, parts are removed and cooled in either a water or an oil bath or in air.

Metal heat treating may be used to develop a surface coating on the metal or to change the physical properties of the bulk metal. Cyanides are most often used in the heat treating operations of carburizing, carbonitriding, and nitriding, which add carbon, nitrogen, or both to the surface of the metal to form a hard surface coating.

2.3 Waste Characterization

This section summarizes the waste characterization data available to the Agency for the F006 through F012 wastes and an estimate of the range of these constituents that may be found in the cyanide-containing P-code wastes. The exact composition of the P-code wastes depends upon the waste matrix (e.g., off-specification chemical, contaminated soil, etc.). The major constituents in the wastes and their approximate concentrations are presented in Table 2-2, which is based on the available waste characterization data summarized in Appendix B. Tables B-1 through B-8 in Appendix B present, by waste code, the concentrations for BDAT list constituents and other parameters identified for the specific wastes. These data were obtained from a variety of sources, as referenced in the tables, including literature sources, EPA sampling and analysis, and data generated from industry.

Table 2-3 presents data on the composition of wastewaters treated in electroplating operations. These data were collected by EPA's Office of Water in the development of Effluent Limitations Guidelines for the metal finishing industry. Treatment of these wastewaters results in the generation of F006 waste.

F006 through F012 wastes contain BDAT metals and cyanides, as well as other inorganic compounds and water. Iron often occurs as a contaminant in these wastes. The concentrations of individual metals in F007, F008,

Table 2-2 Summary of Waste Composition Data for F006-F012 Wastes

Constituent/parameter	Concentration (percent) F006	F007	F008	F009
Cyanide (as NaCN)	<0.1-0.5	5-10	2-10	5-20
BDAT List Metals				
Cadmium	0-2	0-2	0-2	0-2
Chromium	0-30	<0.1	<0.1	<0.1
Copper	0-3	0-1	0-2	0-2
Lead	0-3	<0.1	<0.1	<0.1
Nickel	0-17	0-2	0-2	0-2
Zinc	0-9	0-2	0-2	<0.1
TOTAL BDAT METALS	<0.1-30	-2	-2	-2
BDAT Organics	<0.1	<0.1	<0.1	<0.1
Iron				
Other Non-BDAT Inorganics (primarily sodium carbonate and/or calcium hydroxide)	20-40	20-40	35-40	20
Water	30-80	55-70	55	60-73
Oil and grease	0-4	<0.1	<0.1	<0.1

Constituent/parameter	Concentration (percent) F010	F011	F012	P-codes
Cyanide (as NaCN)	1-4	3-20	<0.1-12	1-50
BDAT List Metals				
Cadmium	-	<0.1	<0.1	-
Chromium	-	<0.1	<0.1	-
Copper	-	<0.1	<0.1	0-50
Lead	-	<0.1	<0.1	-
Nickel	-	<0.1	<0.1	0-50
Zinc	-	<0.1	<0.1	0-50
TOTAL BDAT METALS	<1	0.2	0.1	0-50
BDAT Organics	<0.1	<0.1	<0.1	-
Iron				<0.1
Other Non-BDAT Inorganics (primarily sodium carbonate and/or calcium hydroxide)	1-99	20-80	28-40	-
Water	0	0-77	60	-
Oil and grease	1-99	<0.1	<0.1	-

- = Not available

Table 2-3 Composition of Wastewaters Generated in Electroplating Operations

Constituents	Wastewaters from common metals plating
Inorganics Other Than Metals	
BDAT	
Cyanide (total)	0.005 - 150
Cyanide (amenable)	0.003 - 130
Fluoride	0.022 - 141.7
BDAT List Metals	
Cadmium	0.007 - 21.6
Chromium (total)	0.088 - 525.9
Chromium (hexavalent)	0.005 - 334.5
Copper	0.032 - 272.5
Lead	0.663 - 25.39
Nickel	0.019 - 2954
Zinc	0.112 - 252
Other Parameters	
Iron	0.41 - 1482
Phosphorus	0.02 - 144
Tin	0.06 - 103.4
Total suspended solids	0.10 - 9970

Reference: USEPA 1983.

and F009 wastes are dependent on the type of electroplating solutions used at the particular facility generating the waste. Additionally, F007, F008, F009, and F012 may contain low concentrations of volatile and semivolatile organic compounds as contaminants.

F007, F008, F009, and F011 wastes generally contain from 1 percent cyanide (or approximately 2 percent, as NaCN) up to 15 percent cyanide. These wastes also often contain dissolved metals (especially F007, F008, and F009, which typically contain approximately 2 percent BDAT metals) and must be treated for metals removal by chemical precipitation. F010 wastes may contain high concentrations of oil and grease, as well as cyanide concentrations similar to those of the first group. F006 and F012 are wastewater treatment sludges typically containing less than 1 percent metals in a hydroxide or sulfide sludge. These wastes may contain 5 percent or more cyanide (i.e., 10 percent cyanide (as NaCN) in Table 2-2) but typically contain less than 1,000 ppm cyanide.

F011 and F012 wastes, generated in metal heat treating operations, differ from F007, F008, and F009 generated in electroplating operations, in that they generally do not contain iron complex cyanides. The source of cyanide in metal heat treating operations is the cyanide compounds used in the heat treating bath. These compounds are always the alkali cyanide compounds (sodium cyanide or potassium cyanide). Cyanide is used because it reacts with the surface of the heated parts, forming a hard surface coating. Iron is not likely to be present from the heat-treated parts or the steel tanks. The source of cyanide in electroplating operations is the complexed metal cyanide compound or compounds used as a constituent of the electroplating bath (see Table 2-1). Certain metals are much more soluble in the bath in the complexed form. Iron-cyanide complexes are never added as a constituent of the bath. Electroplaters sometimes attempt to minimize the concentration of iron in these wastes by segregating high-iron content wastewaters and by using rubber-lined tanks (to minimize dissolution of iron from the tank). Some iron will be present in waste electroplating solutions from dissolution of the steel parts being plated. (Iron sometimes dissolves to replace the metal ions plated out of solution.) However, because further reaction of the dissolved iron with cyanide is necessary for formation of the complexes, not all of this iron exists in the complexed iron cyanide form.

The presence of iron, and other metals that form metal-cyanide complexes, may affect treatment of these wastes to the extent that the complexed cyanides are resistant to chemical oxidation treatment. Data are most often available only on the concentration of the metal, and it is seldom the case that the metal is present completely in the complexed form. The iron concentration in the electroplating wastes is higher, in general, than that in the metal heat treating wastes.

The Agency wishes to emphasize that sludges generated from treatment of spent cyanide plating baths may also be classified as F006. An example is a wastewater treatment sludge generated from treatment of a spent cyanide plating solution (an F007 wastewater). This bath solution may be sent through cyanide destruction and chemical precipitation for metals removal separately from other wastewaters. In this case, the precipitated residual would be F007. If the F007 waste were combined with other plant wastes (such as the listed wastes F008 or F009 or electroplating rinsewaters) before cyanide destruction and chemical precipitation treatment in a wastewater treatment system, then the precipitated residual from this treatment would be F006.

In the January 11, 1989, proposed rule, the Agency defined three subcategories of cyanide wastes from the metal finishing industry: Metal Finishing Aqueous Liquids, Metal Finishing Organic Liquids, and Metal Finishing Sludges. The Agency has reexamined the need for categorizing these wastes into these subcategories and believes that it is not necessary to use them. Rather, the Agency has decided that presentation of the treatment standards on a waste code basis (according to the wastewater and nonwastewater forms of the waste) provides a sufficient distinction of the treatability groups.

3. APPLICABLE AND DEMONSTRATED TREATMENT TECHNOLOGIES

This section identifies the treatment technologies that are applicable to F006 through F012 for cyanide and metal constituents and determines which, if any, of the applicable technologies can be considered demonstrated for the purposes of establishing BDAT.

To be applicable, a technology must be theoretically usable to treat the waste in question or to treat a waste that is similar in terms of the parameters that affect treatment selection. To be demonstrated, the technology must be employed in full-scale operation for the treatment of the waste in question or a similar waste. Technologies that are available only at research facilities or at pilot- and bench-scale operations are not considered demonstrated technologies for the purpose of identifying BDAT.

Also in this section, the Agency has provided a description of each of the applicable technologies for cyanide-containing wastes and for dissolved metals and metals within sludges. A description of other treatment technologies can be found in EPA's Treatment Technology Background Document (USEPA 1988c).

3.1 Applicable Treatment Technologies

3.1.1 Cyanides

EPA has identified six technologies as potentially applicable for treatment of cyanides in both wastewaters and nonwastewaters: (1) electrolytic oxidation; (2) chemical oxidation with several oxidizing agents, such as hypochlorite or chlorine (alkaline chlorination), permanganate, ozone, or SO_2/air (Inco process); (3) wet air oxidation; (4) high temperature cyanide hydrolysis; (5) incineration; and (6) stabilization. The first four of these may be followed by chemical precipitation, filtration, and sludge dewatering for metals removal. The first four technologies are most effective in treatment of cyanide in wastes that contain primarily dissolved or soluble cyanide salts, but are also applicable to treatment of wastewater treatment sludges and other solids that contain treatable concentrations of cyanide. Incineration and stabilization are applicable to nonwastewater forms of the wastes.

Electrolytic oxidation followed by alkaline chlorination, chemical oxidation (alkaline chlorination or other methods) alone, electrolytic oxidation alone, wet air oxidation, and high temperature hydrolysis reduce the concentration of cyanide in the wastewaters or nonwastewaters treated. These technologies fully destroy the amenable cyanide present in the waste but treat the complexed cyanides to varying degrees, depending on, among other things, the stability of the metal-cyanide complex and the severity of the oxidizing agent and reaction conditions. Iron cyanide complexes are typically the most resistant to oxidation treatment.

EPA has identified incineration as an applicable technology for treatment of cyanide in F010 wastes containing high concentrations of oil and grease. Incineration is a thermal treatment process that destroys the organic and oxidizable inorganic waste constituents. Incineration of this waste generates an ash and a scrubber water that may require further treatment. Phone contacts with generators of F010 wastes indicate that these wastes may also be treated by an oil/water separation step, followed by recycling or treatment of the oil phase and treatment of the inorganic phase by one of the other cyanide destruction technologies discussed above.

3.1.2 Dissolved Metals

Chemical precipitation treatment of the wastewater residual from cyanide oxidation, followed by filtration of the treated wastewater and dewatering of the precipitated solids, reduces the concentration of metals in the wastewater and concentrates the metals in the treatment sludge in a relatively insoluble form. Filtration and dewatering may also concentrate cyanide in the treatment sludge residual. The treatment sludge metal constituents may then require further treatment by the applicable treatment technologies specified below for metals in nonwastewaters.

3.1.3 Metals in Nonwastewaters

EPA has identified three technologies as potentially applicable for treatment of the metals in wastewater treatment sludges (such as F012 and residuals from treatment of F007-F009 and F011): stabilization, vitrification, and high temperature metals recovery. The first two technologies are designed to reduce the leachability of the metals; the third reduces both the total concentration and the leachability of the metals. Treatment standards for the metal constituents in F006 nonwastewaters have been developed with the First Third of RCRA listed hazardous wastes based on stabilization as BDAT (see 53 FR 31137, August 17, 1988) and thus are not discussed here.

Stabilization may chemically reduce the mobility of metal constituents in a waste. Stabilizing agents, binders, and chemicals are added to a waste to minimize the quantities of metals that leach when the waste is in contact with water. Commonly used stabilization agents include portland cement, lime/pozzolan-based material, and cement kiln dust.

The Agency believes that stabilization is also an applicable technology for the treatment of cyanide in wastewater treatment sludges. However, the Agency believes that stabilization only reduces the leachability of constituents but does not destroy the constituents. Furthermore, the Agency believes that stabilization is suited primarily for stabilizing cationic species (such as some of the BDAT list metals); therefore, it may not treat anionic species (such as cyanide) as effectively as it does metals.

Vitrification has also been identified by the Agency as an applicable technology. A vitrification process can be used to immobilize hazardous constituents in nonwastewaters by producing a vitreous or glass-like mass.

EPA has also identified high temperature metals recovery technologies as applicable. High temperature metals recovery technologies reduce the concentration of some metals in the waste through volatilization and recovery of the volatilized metals and/or the metals remaining in the residual. High temperature metals recovery treatment results in a residual (or slag) that is land disposed.

3.2 Demonstrated Treatment Technologies

3.2.1 Cyanide

Available information shows that electrolytic oxidation followed by alkaline chlorination, alkaline chlorination alone, wet air oxidation, high temperature hydrolysis, SO_2/air oxidation, incineration, and stabilization are demonstrated for treatment of cyanide in electroplating and metal heat treating wastes. The Agency has identified at least one full-scale facility that uses electrolytic oxidation followed by alkaline chlorination to treat cyanide in F011 waste, at least five facilities that use alkaline chlorination to treat cyanide in F006 through F012 wastes, at least one facility that treats cyanide-containing wastes by high temperature cyanide hydrolysis, and one pilot-scale facility that has treated F007 waste by wet air oxidation. In addition, wet air oxidation and SO_2/air oxidation are used to treat similar wastes in full-scale processes.

The Agency also believes that incineration is demonstrated for treatment of F010 wastes, which may contain high concentrations (up to 5 percent) of oil and grease. The Agency is aware of at least one full-scale facility that has treated F010 and similar wastes by incineration.

3.2.2 Metals

EPA believes that chemical precipitation followed by filtration and sludge dewatering is demonstrated at many facilities for treatment of BDAT list metals in F007-F012 wastewaters and similar wastes (such as K062, which was regulated with the First Third of the RCRA-listed hazardous wastes).

Available information also shows that all of the applicable technologies for treatment of BDAT metals in nonwastewaters are demonstrated. The characteristics of F012 wastes and other wastewater treatment sludges (high solids content, substantial concentrations of BDAT list metals, very low concentrations of oil and grease and BDAT list organic constituents) would allow these wastes to be treated by the same methods used for F006. Stabilization is used by at least ten facilities to treat F006 wastes. EPA knows of two full-scale facilities that use metals recovery for F006 wastes and one full-scale facility that treats F006 wastes by vitrification.

3.3 Descriptions of Cyanide Treatment Technologies

3.3.1 Electrolytic Oxidation of Cyanide

(1) Applicability. Electrolytic oxidation is a treatment technology applicable to wastes containing high concentrations of cyanide in solution. Because of excessive retention time requirements, the process is often applied as preliminary treatment for highly concentrated cyanide wastes, prior to more conventional chemical cyanide oxidation (Cushnie 1985).

This treatment technology is used in industry for the destruction of cyanide in (a) concentrated spent plating solutions and stripping solutions, (b) spent heat treating baths, (c) alkaline descalers, and (d) metal passivating (rust-inhibiting) solutions. Electrolytic oxidation has been demonstrated successfully for treatment of wastes containing concentrations of cyanide up to 100,000 mg/l (Easton 1967). However, for concentrations of cyanide lower than 500 mg/l, chemical oxidation treatment may be more efficient. As a result of the inefficiency of this technology for treatment of low-concentration cyanide wastes, it is used only as a pretreatment step if treatment time is a concern.

(2) Underlying principles of operation. The basic principle of electrolytic oxidation of cyanide is that concentrated cyanide waste subject to an electrolytic reaction with dissolved oxygen in an aqueous solution is broken down to the gaseous products carbon dioxide (CO_2), nitrogen (N_2), and ammonia (NH_3). The process is conducted at elevated temperatures for periods ranging from several hours to over a week, depending on the initial cyanide concentration and the desired final cyanide concentration. The theoretical destruction process that takes place at the anodes is described by the following reaction:

$$\underset{\text{cyanide ion}}{2CN^-} + \underset{\text{oxygen}}{2O_2} \xrightarrow{\text{Electricity}} \underset{\text{carbon dioxide}}{2CO_2} + \underset{\text{nitrogen}}{N_2} + \underset{\text{electrons}}{2e^-}$$

The effectiveness of electrolytic oxidation is dependent on the conductivity of the waste, which is a function of several waste characteristics including the concentration of cyanide and other ions in solution. As the process continues, the waste becomes less capable of conducting electricity as cyanide concentration is reduced, causing the electrolytic reaction to be much less efficient at longer retention times.

(3) Description of electrolytic oxidation process. Typically, electrolytic destruction of cyanide takes place in a closed cell. This cell consists of two electrodes suspended in an aqueous solution, with direct current (DC) electricity supplied to drive the reaction to completion. The temperature of the bath containing the cyanide waste is maintained at or above 52°C (125°F). Sodium chloride may be added to the solution as an electrolyte (conductor) to increase the conductivity of the waste being treated. Since the reaction may take days or weeks, water is usually added to the tank periodically to make up for losses resulting from evaporation from the heated tank. This is necessary to ensure that the electrodes remain fully submerged so that a full flow of current is maintained in the solution during treatment. Following treatment, the treated waste is generally further treated in a conventional chemical oxidation system to destroy residual cyanides.

(4) Waste characteristics affecting performance (WCAPs). In determining whether electrolytic oxidation will achieve the same level of performance on an untested waste as on a previously tested waste and whether performance levels can be transferred, EPA examines the following

waste characteristics: (a) the concentration of other oxidizable materials and (b) the concentration of reducible metals.

(a) Concentration of other oxidizable materials. The presence of oxidizable organics (such as oil and grease and surfactants) and the presence of inorganic ionic species in a reduced state (such as trivalent chromium or sulfide) may increase the treatment time required to achieve destruction of cyanide because these materials may be oxidized preferentially to the cyanide in solution. If concentrations of other oxidizable materials are significantly higher in the untested waste than in the tested waste, the system may not achieve the same performance. Longer reaction time may be required to oxidize cyanide and achieve the same treatment performance, or other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(b) Concentration of reducible metals. The electrolytic process may cause some of the more easily reduced metals in the waste, such as copper, to plate out onto the anode as the pure metal. The plating of metals onto the anode may result in changes in current density and, hence, may change the rate of cyanide oxidation. If the concentration of reducible metals in the untested waste is significantly higher than that in the tested waste, the system may not achieve the same performance and other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(5) Design and operating parameters. In assessing the effectiveness of the design and operation of an electrolytic oxidation system, EPA examines the following parameters: (a) the oxidation temperature, (b) the residence time, (c) the pH, (d) the electrical conductivity, (e) the electrode spacing and surface area, and (f) the degree of mixing.

(a) Oxidation temperature. For the electrolytic process, elevated temperatures are used. Normal temperatures range from 52 to 93°C (125 to 200°F). The temperature can be raised by increasing the flow of steam to the coils or jacket supplying heat to the reactor contents. EPA monitors the oxidation temperature to ensure that the system is operating at the appropriate design condition and to diagnose operational problems.

(b) Residence time. Electrolytic oxidation is usually a batch process. The time allowed to complete the reaction is an important factor in electrolysis and is dependent on the initial concentration of the waste and the desired final cyanide concentration. The rate of cyanide destruction decreases as the cyanide concentration decreases (i.e., the rate of cyanide destruction asymptotically approaches zero). Typical residence times range from periods of several hours to more than a week. EPA observes the residence time to ensure that sufficient time is provided to effectively destroy the cyanides in the wastes.

(c) pH. Typical solutions for electrolytic oxidation have a pH ranging from 11.5 to 12.0. The pH must be maintained in the alkaline range to prevent liberation of toxic hydrogen cyanide. Typically, pH is controlled by the addition of caustic or lime. EPA monitors the pH to ensure that the treatment system is operating at the appropriate design condition and to diagnose operational problems.

(d) Electrical conductivity. The solution must have a high enough electrical conductivity to allow the reaction to proceed at an acceptable rate. If the conductivity is not high enough, it can be improved by adding an electrolyte such as sodium chloride. The conductivity of the waste during the reaction is normally determined by monitoring both the current and voltage of the cell. EPA monitors the electrical conductivity to ensure that the treatment system is operating at the appropriate design condition.

(e) Electrode spacing and surface area. The spacing and surface area of the electrodes directly impact the current flowing through the waste. The reaction rate is increased by both closer electrode spacing and more electrode surface area because each increases the current density in the cell. EPA observes the electrode spacing and surface area to ensure that sufficient current density is provided to effectively destroy the cyanides in the waste.

(f) Degree of mixing. Electrolytic destruction of cyanide requires good mixing in the reaction vessel. Mixing helps ensure an adequate supply of oxygen (from the air) for the electrochemical reaction (see Section 3.3.1 (2) Underlying Principles of Operation), enhances mass transfer to promote the oxidation reaction, and keeps suspended solids in suspension. Mixing may be provided by the bubbling of air from the bottom of the reactor, or an external source of mixing may be provided. The quantifiable degree of mixing is a complex assessment that includes, among other factors, the amount of energy supplied, the length of time the material is mixed, and the related turbulence effects of the size and shape of the reaction vessel used. This is beyond the scope of simple measurement. EPA, however, evaluates the degree of mixing qualitatively by considering whether mixing is provided and whether the type of mixing device is one that could be expected to achieve uniform mixing of the waste.

3.3.2 Chemical Oxidation

(1) Applicability. Chemical oxidation is a treatment technology used to treat wastes containing organics. In addition, it is used to treat sulfide wastes by converting the sulfide to sulfate. Also, the destruction of cyanides in wastes can be accomplished by chemical oxidation.

Chemical oxidation of cyanide is applicable for dissolved cyanides in aqueous solutions, such as wastewaters from metal plating and finishing operations, or for inorganic sludges from these operations that contain soluble cyanide compounds. Chemical oxidation is most applicable to cyanides that are in a form that can be easily dissociated in water to yield free cyanide ions. If the cyanide is present in water as a tightly bound iron cyanide complex ion (ferrocyanide or ferricyanide), only limited treatment may occur.

Chemical oxidation may also be used in treatment of complexed metal wastes. Organic compounds such as EDTA, NTA, citric acid, glutaric acid, lactic acid, and tartarates are often used as chelating agents to prevent metal ions from precipitating out in electroless plating solutions. When these spent plating solutions require treatment for metals removal by chemical precipitation, the organic chelating agents must first be destroyed. Chemical oxidants, potassium permanganate in particular, are effective in releasing metals from complexes with these organic compounds (Schroeter and Painter 1987).

(2) Underlying principles of operation. The basic principle of chemical oxidation is that inorganic cyanides, some dissolved organic compounds, and sulfides can be chemically oxidized to yield carbon dioxide, water, salts, simple organic acids, and, in the case of sulfides, sulfates. The principal chemical oxidants used are hypochlorite, chlorine gas, chlorine dioxide, hydrogen peroxide, ozone, and potassium permanganate. The reaction chemistry for each is discussed below.

(a) Oxidation with hypochlorite or chlorine (alkaline chlorination). This type of oxidation is carried out using sodium hypochlorite ($NaOCl$), calcium hypochlorite ($Ca(OCl)_2$), chlorine gas (Cl_2), or sometimes chlorine dioxide gas (ClO_2). The reactions are normally conducted under slightly or moderately alkaline conditions. Alkaline chlorination of cyanide is a two-step process usually operated at a pH of 10 to 11.5 for the first step and 8.5 for the second step.

The toxic gas cyanogen chloride (CNCl) is formed as a reaction intermediate in the first step of this process and may be liberated if the pH is less than 10 and incomplete reaction occurs. Example reactions for the oxidation of cyanide, phenol, and sulfide using sodium hypochlorite are shown below:

Cyanide: $CN^- + NaOCl \rightarrow OCN^- + NaCl$ (Step 1)

$2OCN^- + 3NaOCl \rightarrow CO_3^{2-} + CO_2 + N_2 + 3NaCl$ (Step 2)

Phenol: $C_6H_5OH + 14NaOCl \rightarrow 6CO_2 + 3H_2O + 14NaCl$

Sulfide: $S^= + 4NaOCl \rightarrow SO_4^= + 4NaCl$

Chlorine dioxide also oxidizes the same pollutants under identical conditions. Chlorine dioxide first hydrolyzes to form a mixture of chlorous ($HClO_2$) and chloric ($HClO_3$) acids. These acids act as the oxidants, as shown in the equations below for phenol:

$$2ClO_2 + H_2O \rightarrow HClO_2 + HClO_3$$

$$C_6H_5OH + 7HClO_2 \rightarrow 6CO_2 + 3H_2O + 7HCl$$

$$3C_6H_5OH + 14HClO_3 \rightarrow 18CO_2 + 9H_2O + 14HCl$$

(b) Peroxide oxidation. Peroxide oxidizes the same constituents that alkaline chlorination oxidizes under similar conditions. The relevant reactions are:

Cyanide: $2CN^- + 5H_2O_2 \rightarrow 2CO_2 + N_2 + 4H_2O + 2OH^-$

Phenol: $C_6H_5OH + 14H_2O_2 \rightarrow 6CO_2 + 17H_2O$

Sulfide: $S^= + 4H_2O_2 \rightarrow SO_4^= + 4H_2O$

(c) Oxidation with ozone (ozonation). Ozone is an effective oxidizing agent for treatment of organic compounds and for the oxidation of cyanide to cyanate. Cyanogen gas (C_2N_2) is a reaction intermediate in this reaction. Further oxidation of cyanate to carbon dioxide and nitrogen compounds (N_2 or NH_3) occurs slowly with ozone. The oxidation of cyanide to cyanate proceeds by the following reaction:

$$CN^- + O_3 \rightarrow CNO^- + O_2$$

The rates of ozonation reactions can be accelerated by supplying ultraviolet (UV) radiation during treatment. Some literature sources indicate that even the most difficult cyanide complexes to treat, the iron-cyanide complexes, can be oxidized completely.

(d) Oxidation with potassium permanganate. Potassium permanganate can also be used to oxidize the same constituents as the other chemical oxidants. The reactions of potassium permanganate with phenol and sulfide at acidic pHs and with cyanide at a pH of 12 to 14 are as follows:

Phenol: $3C_6H_5OH + 28KMnO_4 + 28H^+ \rightarrow 18CO_2 + 28MnO_2 + 23H_2O + 28K^+$

Sulfide: $5S^= + 8KMnO_4 + 24H^+ \rightarrow 5SO_4^= + 8Mn^{+2} + 12H_2O + 8K^+$

Cyanide: $CN^- + 2KMnO_4 + Ca(OH)_2 \rightarrow CNO^- + K_2MnO_4 + CaMnO_4 + H_2O$

In cyanide oxidation using potassium permanganate, cyanide is oxidized only to cyanate. Further oxidation of cyanate can be accomplished by acid hydrolysis or by the use of another oxidizing agent.

(e) SO_2/air oxidation. Cyanide can be oxidized to cyanate in an aqueous solution by bubbling air containing from 1 to 10 percent SO_2 through the waste. The SO_2 is also oxidized to sulfate in this reaction. Soluble sulfite salts (such as Na_2SO_3) can be used as a source of oxidizable sulfur rather than SO_2 gas. This treatment process occurs by the following reaction:

$$CN^- + SO_2 + O_2 + H_2O \rightarrow CNO^- + H_2SO_4$$

This oxidation reaction requires the use of a soluble copper salt catalyst. Copper sulfate ($CuSO_4$) is most often used. SO_2/air oxidation is used frequently in the treatment of wastewaters from gold production, which contain both cyanide and thiocyanate, because SO_2/air oxidizes cyanide more strongly than thiocyanate while alkaline chlorination and other common oxidizing agents oxidize thiocyanate more strongly than cyanide. As with potassium permanganate, further oxidation of cyanate can be accomplished by acid hydrolysis or by the use of another oxidizing agent.

(3) Description of chemical oxidation processes

(a) Alkaline chlorination. Alkaline chlorination can be accomplished by either batch or continuous processes. For batch treatment, the wastewater is transferred to a reaction tank, where the pH is adjusted and the oxidizing agent is added. In some cases, the tank may be heated to increase the reaction rate. For oxidation of most compounds, a slightly to moderately alkaline pH is used. It is important that the tank be well mixed for effective treatment to occur. After treatment, the wastewater is either directly discharged or transferred to another process for further treatment.

In the continuous process, automatic instrumentation is used to control pH, reagent addition, and temperature. An oxidation-reduction potential (ORP) sensor is usually used to measure the extent of reaction.

In both types of processes, agitation is typically provided to maintain thorough mixing. Typical residence times for these and other oxidation processes depend on the concentration of the constituents to be treated and usually range from 1 to 2 hours.

(b) Peroxide oxidation. The peroxide oxidation process is run under similar conditions, and with similar equipment, to those used in the alkaline chlorination process. Hydrogen peroxide is added as a liquid solution.

(c) Ozonation. Ozonation can be conducted in a batch or continuous process. The ozone for treatment is produced onsite because of the hazards of transporting and storing ozone as well as its short shelf life. The ozone gas is supplied to the reaction vessels by injection into the wastewater. The batch process uses a single reaction tank. As with alkaline chlorination, the amount of ozone added and the reaction time used are determined by the type and concentration of the oxidizable contaminants, and vigorous mixing should be provided for complete oxidation.

In continuous operation, two separate tanks may be used for reaction. The first tank receives an excess dosage of ozone. Any excess ozone remaining at the outlet of the second tank is recycled to the first tank, thus ensuring that an excess of ozone is maintained and also that no ozone is released to the atmosphere. As with alkaline chlorination, an ORP control system is usually necessary to ensure that sufficient ozone is being added.

(d) Permanganate oxidation. Permanganate oxidation is conducted in tanks in a manner similar to that used for alkaline chlorination, as discussed previously. Potassium permanganate is normally dissolved in an auxiliary tank and added as a solution. As with the other oxidizing agents, ORP (for continuous processes) and excess oxidizing agent (for batch processes) are monitored to measure the extent of reaction.

(e) SO_2/air oxidation. SO_2/air oxidation of cyanide depends on efficient mixing of air with the waste to ensure an adequate supply of oxygen. Because of this factor, the equipment requirements for this process are similar to those of ozonation. SO_2 is sometimes supplied with the air by using flue gas containing SO_2 as the air source. Otherwise, sulfur in the +4 oxidation state can be fed as gaseous sulfur dioxide (SO_2), liquid sulfurous acid (H_2SO_3), sodium sulfite (Na_2SO_3) solution, or sodium bisulfite ($NaHSO_3$) solution. Sodium bisulfite solution, made by dissolving sodium metabisulfite ($Na_2S_2O_5$) in water, is the most frequently used source of SO_2. This process is usually run continuously, with the addition of oxidizing agent and acid/alkali being controlled through continuous monitoring of ORP and pH, respectively.

(4) Waste characteristics affecting performance (WCAPs). In determining whether chemical oxidation will achieve the same level of performance on an untested waste as on a previously tested waste and whether performance levels can be transferred, EPA examines the following waste characteristics: (a) the concentration of other oxidizable contaminants (b) the concentration of metal salts, and (c) the concentration of complexed metals.

(a) Concentration of other oxidizable compounds. The presence of other oxidizable compounds in addition to the BDAT constituents of concern will increase the demand for oxidizing agents and, hence, potentially reduce the effectiveness of the treatment process. As a surrogate for the amount of oxidizable organics present, EPA analyzes for total organic carbon (TOC) in the waste. Oil and grease also provides an indication of the amount of oxidizable organics present. Inorganic reducing compounds such as sulfide may also create a demand for additional oxidizing agent; EPA also attempts to identify and analyze for these constituents. If TOC and/or inorganic reducing compound concentrations in the untested waste are significantly higher than those in the tested waste, the system may not achieve the same performance. Additional oxidizing agent may be required to effectively oxidize the waste and achieve the same treatment performance. Other, more applicable treatment technologies also may need to be considered for treatment of the untested waste.

(b) Concentration of metal salts. Metal salts, especially lead and silver salts, will react with the oxidizing agent(s) to form metal peroxides, chlorides, hypochlorites, and/or chlorates. These reactions can cause an excessive consumption of oxidizing agents and potentially interfere with the effectiveness of treatment.

(c) Concentration of complexed metals. An additional problem with metals in cyanide solutions is that metal-cyanide complexes are sometimes formed. These complexes are negatively charged metal-cyanide ions that are extremely soluble. Cyanide in the complexed form may not be oxidizable, depending on the strength of the metal-cyanide bond in the complex and the type of oxidizing agent used. Iron complexes (for example, the ferrocyanide ion, $Fe(CN)_6^{-4}$) are the most stable of the complexed cyanides.

If the concentrations of metal salts and/or metal-cyanide complexes in the untested waste are significantly higher than those in the tested waste, the system may not achieve the same performance. Additional oxidizing agent and/or a different oxidizing agent may be required to effectively oxidize the waste and achieve the same treatment performance. When the waste contains high concentrations of metal-cyanide complexes that are resistant to chemical oxidation treatment, other treatment technologies may need to be considered for treatment of the untested waste.

(5) Design and operating parameters. In assessing the effectiveness of the design and operation of a chemical oxidation system, EPA examines the following parameters: (a) the residence time, (b) the amount and type of oxidizing agent, (c) the degree of mixing, (d) the pH, (e) the oxidation temperature, and (f) the amount and type of catalyst.

(a) Residence time. The residence time impacts the extent of volatilization of waste contaminants. For a batch system, the residence time is controlled by adjusting the treatment time in the reaction tank. For a continuous system, the waste feed rate is controlled to make sure that the system is operated at the appropriate design residence time. EPA monitors the residence time to ensure that sufficient time is provided to effectively oxidize the waste.

(b) Amount and type of oxidizing agent. Several factors influence the choice of oxidizing agents and the amount to be added. The amount of oxidizing agent required to treat a given amount of oxidizable constituent(s) will vary with the agent chosen. Enough oxidant must be added to ensure complete oxidation; the specific amount will depend on the type of oxidizable compounds in the waste and the chemistry of the oxidation reactions. Theoretically, the amount of oxidizing agent to be added can be computed from oxidation reaction stoichiometry; in practice, an excess of oxidant should be used. Testing for excess oxidizing agent will determine whether the reaction has reached completion. In continuous processes, the addition of oxidizing agent is accomplished by automated feed methods. The amount of oxidizing agent needed is usually measured and controlled automatically by an oxidation-reduction potential (ORP) sensor. EPA examines the amount of oxidant added to the chemical oxidation system to ensure that it is sufficient to effectively oxidize the waste and, for continuous processes, examines how the facility ensures that the particular addition rate is maintained. EPA also tests for excess oxidizing agent for batch processes and continuously monitors the ORP for continuous processes to ensure that excess oxidizing agent, if possible, is supplied.

(c) Degree of mixing. Process tanks must be equipped with mixers to ensure maximum contact between the oxidizing agent and the waste solution. Proper mixing also limits the production of any solid precipitates from side reactions that may resist oxidation. Mixing also provides an even distribution of tank contents and a homogeneous pH throughout the waste, improving oxidation of wastewater constituents. The quantifiable degree of mixing is a complex assessment that includes, among other things, the amount of energy supplied, the length of time the material is mixed, and the related turbulence effects of the specific size and shape of the tank. This is beyond the scope of simple measurement. EPA, however, evaluates the degree of mixing qualitatively by considering whether mixing is provided and whether the type of mixing device is one that could be expected to achieve uniform mixing of the waste solution.

(d) pH. Operation at the optimal pH maximizes the chemical oxidation reactions and may, depending on the oxidizing agent being used, limit the formation of undesirable reaction byproducts or the escape of cyanide from solution as HCN, CNCl, or C_2N_2 gas. The pH is controlled by the addition of caustic, lime, or acid to the solution. In most cases, a slightly or moderately alkaline pH is used, depending on the type of oxidizing agent being used and the compound being treated (see Section 3.3.2 (2), Underlying Principles of Operation). In alkaline chlorination treatment of organics, a slightly acidic pH may be selected as an optimum. In permanganate oxidation, a pH of 2 to 4 is often selected. EPA monitors the pH continuously, if possible, to ensure that the system is operating at the appropriate design condition and to diagnose operational problems.

(e) Oxidation temperature. Temperature affects the rate of reaction and the solubility of the oxidizing agent in the waste. As the temperature is increased, the solubility of the oxidizing agent, in most instances, is increased and the required residence time, in most cases, is reduced. EPA monitors the oxidation temperature continuously, if possible, to ensure that the system is operating at the appropriate design condition and to diagnose operational problems.

(f) Amount and type of catalyst. Adding a catalyst that promotes oxygen transfer and thus enhances oxidation has the effect of lowering the necessary reactor temperature and/or improving the level of destruction of oxidizable compounds. For waste constituents that are more difficult to oxidize, catalyst addition may be necessary to effectively destroy the constituent(s) of concern. Catalysts typically used for this purpose include copper bromide and copper nitrate. If a catalyst is required, EPA examines the amount and type added, as well as the method of addition of the catalyst to the waste, to ensure that effective oxidation is achieved.

3.3.3 Wet Air Oxidation

(1) Applicability. Wet air oxidation is a treatment technology applicable to wastewaters containing organics and oxidizable inorganics such as cyanide. The process is typically used to oxidize sewage sludge, regenerate spent activated carbon, and treat process wastewaters. Wastewaters treated using this technology include pesticide wastes, petrochemical process wastes, cyanide-containing metal finishing wastes, spent caustic wastewaters containing phenolic compounds, and some organic chemical production wastewaters.

This technology differs from other treatment technologies generally used to treat wastewaters containing organics in several ways. First, wet air oxidation can be used to treat wastewaters that have higher organic concentrations than are normally handled by biological treatment, carbon adsorption, and chemical oxidation, but may be too dilute to be effectively treated by thermal processes such as incineration. Wet air oxidation is most applicable for waste streams containing dissolved or suspended organics in the 500 to 15,000 mg/l range. Below 500 mg/l, the rates of wet air oxidation of most organic constituents are too slow for efficient application of this technology. For these more dilute waste streams, biological treatment, carbon adsorption, or chemical oxidation may be more applicable. For more concentrated waste streams (above 15,000 mg/l), thermal processes such as incineration may be more applicable. Second, wet air oxidation can be applied to wastes that have significant concentrations of metals (roughly 2 percent), whereas biological treatment, carbon adsorption, and chemical oxidation may have difficulty in treating such wastes.

It is important to point out that wet air oxidation proceeds by a series of reaction steps and the intermediate products formed are not always as readily oxidized as are the original constituents. Therefore, the process does not always achieve complete oxidation of the organic constituents. Accordingly, in applying this technology it is important to assess potential products of incomplete oxidation to determine whether further treatment is necessary or whether this technology is appropriate at all.

Studies of the wet air oxidation of different compounds have led to the following empirical observations concerning the susceptibility of a compound to wet air oxidation based on its chemical structure:

1. Aliphatic compounds, even with multiple halogen atoms, can be destroyed within conventional wet air oxidation conditions. Oxygenated compounds (such as low molecular weight alcohols, aldehydes, ketones, and carboxylic acids) are formed, but these compounds are readily biotreatable.

2. Aromatic hydrocarbons, such as toluene, acenaphthene, or pyrene, are easily oxidized.

3. Halogenated aromatic compounds can be oxidized provided there is at least one nonhalogen functional group present on the ring (e.g., pentachlorophenol (-OH) or 2,4,6-trichloroaniline ($-NH_2$)).

4. Halogenated aromatic compounds, such as 1,2-dichlorobenzene, and PCBs, such as Aroclor 1254, are resistant to wet air oxidation under conventional conditions.

5. Halogenated ring compounds, such as the pesticides aldrin, dieldrin, and endrin, are expected to be resistant to conventional wet air oxidation.

6. DDT can be oxidized, but results in the formation of intractable oils in conventional wet air oxidation.

7. Heterocyclic compounds containing oxygen, nitrogen, or sulfur are expected to be destroyed by wet air oxidation because the O, N, or S atoms provide a point of attack for oxidation reactions to occur.

(2) Underlying principles of operation. The wet air oxidation of aqueous wastes occurs at high temperatures and pressures. The typical operating temperature for the treatment process ranges from 175 to 325°C (347 to 617°F). The pressure is maintained at a level high enough to prevent excessive evaporation of the liquid phase at the operating temperature, generally between 300 and 3000 psi. At these elevated temperatures and pressures, the solubility of oxygen in water is dramatically increased, thus providing a strong driving force for the oxidation. The reaction must take place in the aqueous phase because the chemical reactions involve both oxygen (oxidation) and water (hydrolysis). The wet air oxidation process for a specific organic compound generally involves a number of oxidation and hydrolysis reactions in series, which degrade the initial compound by steps into a

series of compounds of simpler structure. Complete wet air oxidation results in the conversion of hazardous compounds into carbon dioxide, water vapor, ammonia (for nitrogen-containing wastes), sulfate (for sulfur-containing wastes), and halogen acids (for halogenated wastes).

However, treatable quantities of partial degradation products may remain in the treated wastewaters from wet air oxidation. Therefore, effluents from wet air oxidation processes may be given subsequent treatment including biological treatment, carbon adsorption, or chemical oxidation before being discharged.

(3) Description of wet air oxidation process. A conventional wet air oxidation system consists of a high-pressure liquid feed pump, an oxygen source (air compressor or liquid oxygen vaporizer), a reactor, heat exchangers, a vapor-liquid separator, and process regulators. A basic flow diagram is shown in Figure 3-1.

A typical batch wet air oxidation process proceeds as follows. First, a copper catalyst solution may be mixed with the aqueous waste stream if preliminary testing indicates that a catalyst is necessary. The waste is then pumped into the reaction chamber. The aqueous waste is pressurized and heated to the design pressure and temperature. After reaction conditions have been established, air is fed to the reactor for the duration of the design reaction time. At the completion of the wet air oxidation process, suspended solids or gases are removed and the remaining treated aqueous waste is either discharged directly or fed to a biological treatment, carbon adsorption, or chemical oxidation treatment system if further treatment is necessary prior to discharge.

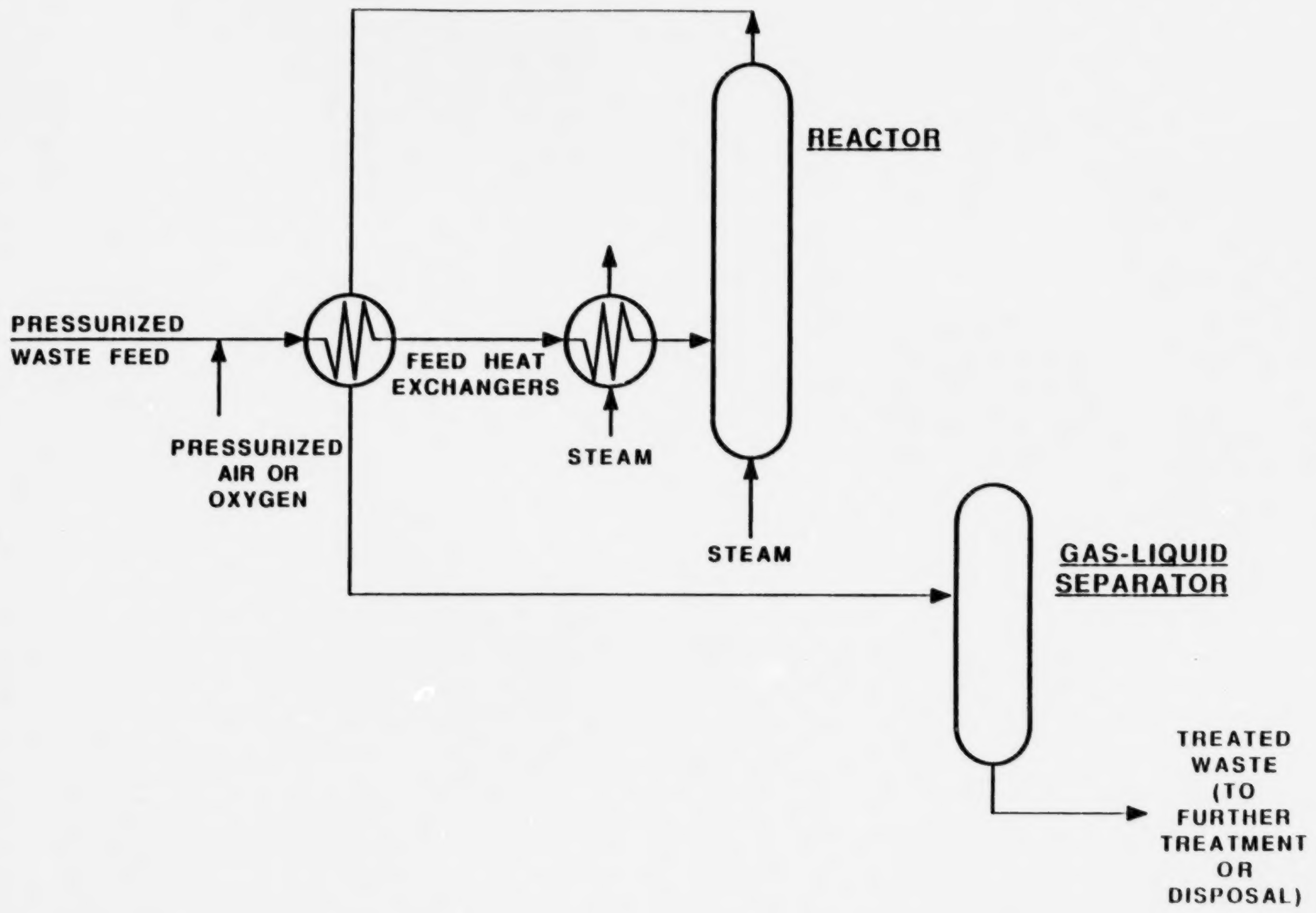

PRESSURIZED
WASTE FEED
PRESSURIZED
AIR OR
OXYGEN
FEED HEAT
EXCHANGERS
STEAM
REACTOR
STEAM
GAS-LIQUID
SEPARATOR
TREATED
WASTE
(TO
FURTHER
TREATMENT
OR
DISPOSAL)

FIGURE 3-1. WET AIR OXIDATION PROCESS FLOW DIAGRAM

Wet air oxidation can also be operated in a continuous process. In continuous operation, the waste is pressurized, mixed with pressurized air or oxygen, preheated in a series of heat exchangers by the hot reactor effluent and steam, and fed to the reactor. The waste feed flow rate controls the reactor residence time. Steam is fed into the reactor column to adjust the column temperature. The treated waste is separated in a gas-liquid separator, with the gases treated in an air pollution control system and/or discharged to the atmosphere and the liquids either further treated, as mentioned above, and/or discharged to disposal.

(4) Waste characteristics affecting performance (WCAPs). In determining whether wet air oxidation will achieve the same level of performance on an untested waste as on a previously tested waste and whether performance levels can be transferred, EPA examines the following waste characteristics: (a) the chemical oxygen demand and (b) the concentration of interfering substances.

(a) Chemical oxygen demand. The chemical oxygen demand (COD) of the waste is a measure of the oxygen required for complete oxidation of the oxidizable waste constituents. The limit to the amount of oxygen that can be supplied to the waste is dependent on the solubility of oxygen in the aqueous waste and the rate of transfer of oxygen from the gas phase to the liquid phase. This sets an upper limit on the amount of oxidizable compounds that can be treated by wet air oxidation. Thus, high-COD wastes may require dilution for effective treatment to occur. If the COD of the untested waste is significantly higher than that of the tested waste, the system may not achieve the same performance. Pretreatment of the waste or dilution as part of treatment may be needed to reduce the COD to within levels treatable by the dissolved oxygen concentration and to achieve the same treatment performance, or other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(b) Concentration of interfering substances. In some cases, addition of a water-soluble copper salt catalyst to the waste before processing is necessary for efficient oxidation treatment (for example, for oxidation of some halogenated organics). Other metals have been tested and have been found to be less effective. Interfering substances for the wet air oxidation process are essentially those that cause the formation of insoluble copper salts when copper catalysts are used. To be effective in catalyzing the oxidation reaction, the copper ions must be dissolved in solution. Sulfide, carbonate, and other negative ions that form insoluble copper salts may interfere with treatment effectiveness if they are present in significant concentrations in wastes for which copper catalysts are necessary for effective treatment. If an untested waste for which a copper catalyst is necessary for effective treatment has a concentration of interfering substances (including sulfide, carbonate, or other anions that form insoluble copper salts) significantly higher than that in a tested waste, the system may not achieve the same performance and other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(5) Design and operating parameters. In assessing the effectiveness of the design and operation of a wet air oxidation system, EPA examines the following parameters: (a) the oxidation temperature, (b) the residence time, (c) the excess oxygen concentration, (d) the oxidation pressure, and (e) the amount and type of catalyst. Optimization of these parameters is often first performed on bench scale using an autoclave, and then refined in a pilot-scale system.

(a) Oxidation temperature. Temperature is the most important parameter affecting the system. The design temperature must be high enough to allow the oxidation reactions to proceed at acceptable rates. Raising the temperature increases the wet air oxidation rate by enhancing oxygen solubility and oxygen diffusivity. The process is normally operated in the temperature range of 175 to 325°C (347 to 617°F), depending on the hazardous constituent(s) to be treated. EPA monitors the oxidation temperature continuously, if possible, to ensure that the system is operating at the appropriate design condition and to diagnose operational problems.

(b) Residence time. The residence time impacts the extent of oxidation of waste contaminants. For a batch system, the residence time is controlled directly by adjusting the treatment time in the reaction tank. For a continuous system, the waste feed rate is controlled to make sure that the system is operated at the appropriate design residence time. Generally, the reaction rates are relatively fast for the first 30 minutes and become slow after 60 minutes. Typical residence times, therefore, are approximately 1 hour. EPA monitors the residence time to ensure that sufficient time is provided to effectively oxidize the waste.

(c) Excess oxygen concentration. The system must be designed to supply adequate amounts of oxygen for the compounds to be oxidized. An estimate of the amount of oxygen needed can be made based on the COD content of the untreated waste; excess oxygen should be supplied to ensure complete oxidation. The source of oxygen is compressed air or a high-pressure pure oxygen stream. EPA monitors the excess oxygen concentration (the concentration of oxygen in the gas leaving the reactor) continuously, if possible, by sampling the vent gas from the gas-liquid separator to ensure that an effective amount of oxygen or air is being supplied to the waste.

(d) Oxidation pressure. The design pressure must be high enough to prevent excessive evaporation of water and volatile organics at the design temperature. This allows the oxidation reaction to occur in the aqueous phase, thereby improving treatment effectiveness. EPA monitors the oxidation pressure continuously, if possible, to ensure that the system is operating at the appropriate design condition and to diagnose operational problems.

(e) Amount and type of catalyst. Adding a catalyst that promotes oxygen transfer and thus enhances oxidation has the effect of lowering the necessary reactor temperature and/or improving the level of destruction of oxidizable compounds. For waste constituents that are more difficult to oxidize, the addition of a catalyst may be necessary to effectively destroy the constituent(s) of concern. Catalysts typically used for this purpose include copper bromide and copper nitrate. If a catalyst is required, EPA examines the amount and type added, as well as the method of addition of the catalyst to the waste, to ensure that effective oxidation is achieved.

3.3.4 Incineration

This section addresses the commonly used incineration technologies: liquid injection, rotary kiln, fluidized bed, and fixed hearth. As appropriate, the subsections are divided by type of incineration unit.

(1) Applicability

(a) Liquid injection. Liquid injection is applicable to wastes that have viscosity values low enough that the waste can be atomized in the combustion chamber. A range of literature maximum viscosity values are reported, with the low being 100 Saybolt Seconds Universal (SSU) and the high being 10,000 SSU. It is important to note that viscosity is temperature dependent so that while liquid injection may not be applicable to a waste at ambient conditions, it may be applicable when the waste is heated. Other factors that affect the use of liquid injection are particle size and the presence of suspended solids. Both of these can cause plugging of the burner nozzle.

(b) Rotary kiln/fluidized bed/fixed hearth. These incineration technologies are applicable to a wide range of hazardous wastes. They can be used on wastes that contain high or low total organic content, high or low filterable solids, various viscosity ranges, and a range of other waste parameters. EPA has not found these technologies to be demonstrated on most wastes that are composed essentially of metals with low organic concentrations. In addition, the Agency expects that the incineration of some of the high metal content wastes may not be compatible with existing and future air emission limits without emission controls far more extensive than those currently in use.

(2) Underlying principles of operation

(a) Liquid injection. The basic operating principle of this incineration technology is that incoming liquid wastes are volatilized and then additional heat is supplied to the waste to destabilize the chemical bonds. Once the chemical bonds are broken, these constituents react with oxygen to form carbon dioxide and water vapor. The energy needed to destabilize the bonds is referred to as the energy of activation.

(b) Rotary kiln and fixed hearth. There are two distinct principles of operation for these incineration technologies, one for each of the two chambers involved. In the primary chamber, energy, in the form of heat, is transferred to the waste to achieve volatilization of the various organic waste constituents. During this volatilization process some of the organic constituent bonds destabilize and oxidize to carbon dioxide and water vapor. In the secondary chamber, additional heat is supplied to overcome the energy requirements needed to destabilize the remaining chemical bonds and allow the constituents to react with excess oxygen to form carbon dioxide and water vapor. The principle of operation for the secondary chamber is similar to that of liquid injection.

(c) Fluidized bed. The principle of operation for this incinerator technology is somewhat different from that for rotary kiln and fixed hearth incineration, in that there is only one chamber, which contains the fluidizing sand and a freeboard section above the sand. The purpose of the fluidized bed is to both volatilize the waste and combust the waste. Destruction of the waste organics can be accomplished to a better degree in this chamber than in the primary chamber of the rotary kiln and fixed hearth because of (i) improved heat transfer from fluidization of the waste using forced air and (ii) the fact that the fluidization process provides sufficient oxygen and turbulence to convert the organics to carbon dioxide and water vapor. The freeboard volume generally does not have an afterburner; however, additional time is provided for conversion of the organic constituents to carbon dioxide and water vapor (and hydrochloric acid if chlorine is present in the waste).

(3) Description of incineration technologies

(a) Liquid injection. The liquid injection system is capable of incinerating a wide range of gases and liquids. The combustion system has a simple design with virtually no moving parts. A burner or nozzle atomizes the liquid waste and injects it into the combustion chamber, where it burns in the presence of air or oxygen. A forced draft system supplies the combustion chamber with air to provide oxygen for combustion and turbulence for mixing. The combustion chamber is usually a cylinder lined with refractory (i.e., heat-resistant) brick, and it can be fired horizontally, vertically upward, or vertically downward. Figure 3-2 illustrates a liquid injection incineration system.

(b) Rotary kiln. A rotary kiln is a slowly rotating, refractory-lined cylinder that is mounted at a slight incline from the horizontal (see Figure 3-3). Solid wastes enter at the high end of the kiln, and liquid or gaseous wastes enter through atomizing nozzles in the kiln or afterburner section. Rotation of the kiln exposes the solids to the heat, vaporizes them, and allows them to combust by mixing with air. The rotation also causes the ash to move to the lower end of the kiln, where it can be removed. Rotary kiln systems usually have a secondary combustion chamber or afterburner following the kiln for further combustion of the volatilized components of solid wastes.

(c) Fluidized bed. A fluidized bed incinerator consists of a column containing inert particles such as sand, which is referred to as the bed. Air, driven by a blower, enters the bottom of the bed to fluidize the sand. Air passage through the bed promotes rapid and uniform mixing of the injected waste material within the fluidized bed. The fluidized bed has an extremely high heat capacity (approximately three times that of flue gas at the same temperature), thereby providing a large heat reservoir. The injected waste reaches ignition temperature quickly in the hot fluidized bed. Continued bed agitation by the fluidizing air allows larger particles to remain suspended in the combustion zone (see Figure 3-4).

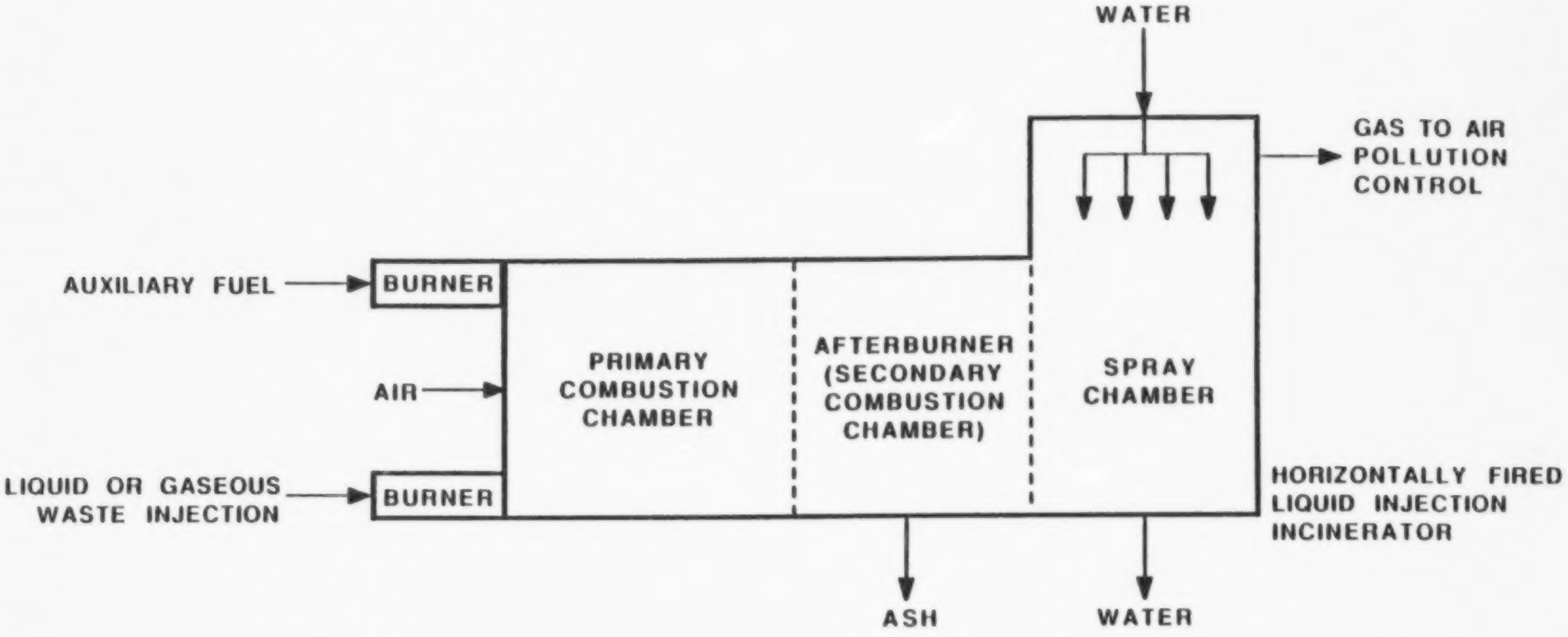

WATER
GAS TO AIR
POLLUTION
CONTROL
AUXILIARY FUEL
BURNER
AIR
LIQUID OR GASEOUS
WASTE INJECTION
BURNER
PRIMARY
COMBUSTION
CHAMBER
AFTERBURNER
(SECONDARY
COMBUSTION
CHAMBER)
SPRAY
CHAMBER
HORIZONTALLY FIRED
LIQUID INJECTION
INCINERATOR
ASH
WATER

FIGURE 3-2. LIQUID INJECTION INCINERATOR

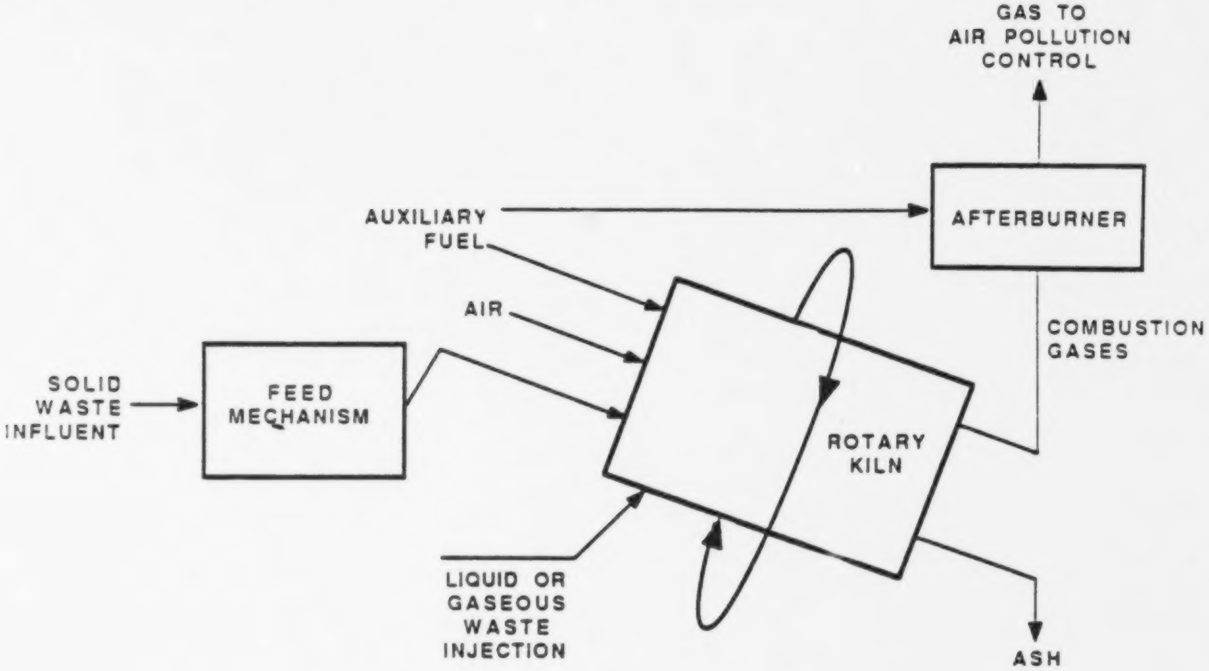

GAS TO
AIR POLLUTION
CONTROL
AUXILIARY
FUEL
AFTERBURNER
AIR
COMBUSTION
GASES
SOLID
WASTE
INFLUENT
FEED
MECHANISM
ROTARY
KILN
LIQUID OR
GASEOUS
WASTE
INJECTION
ASH

FIGURE 3-3. ROTARY KILN INCINERATOR

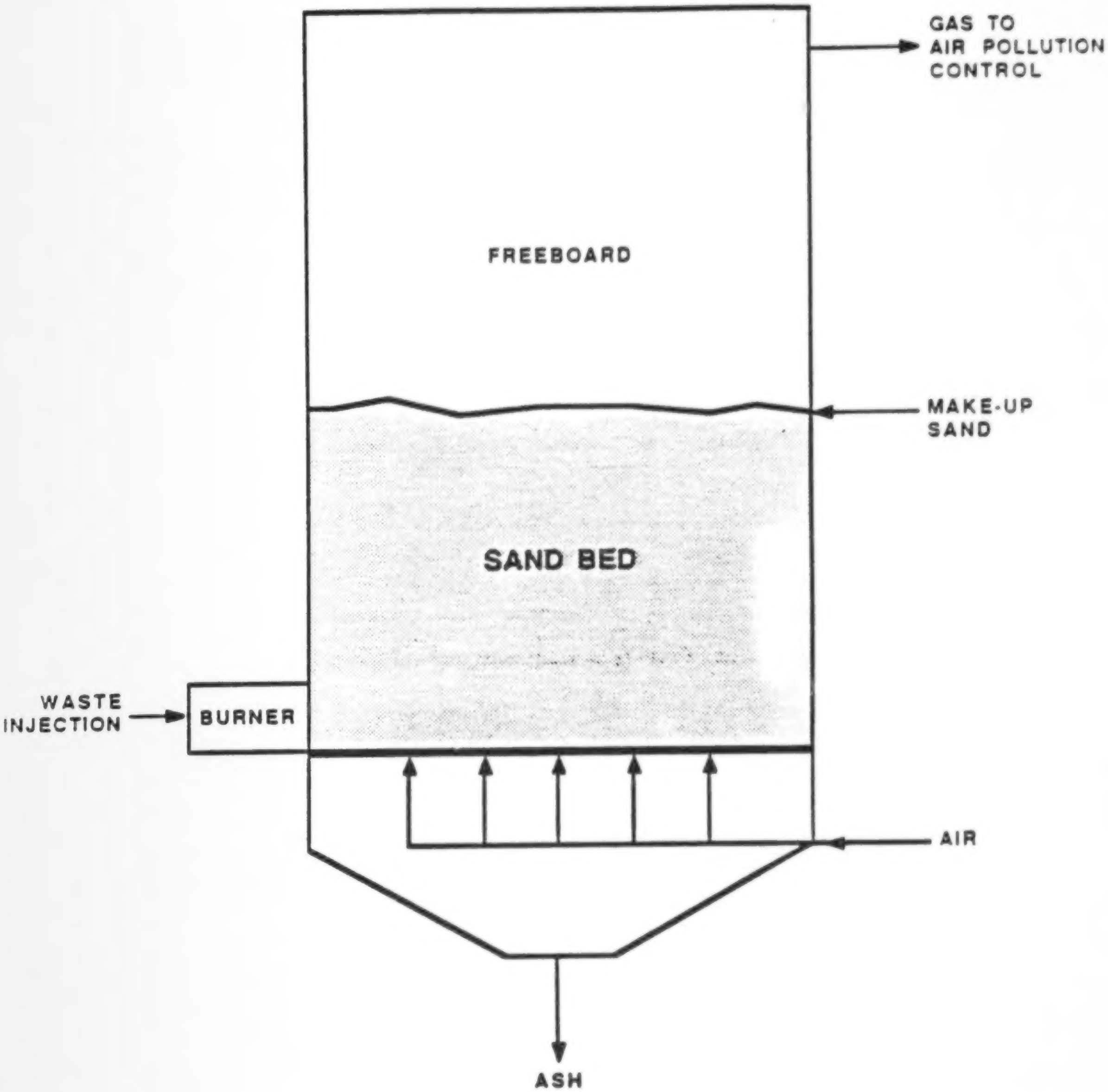

GAS TO AIR POLLUTION CONTROL
FREEBOARD
MAKE-UP SAND
SAND BED
WASTE INJECTION
BURNER
AIR
ASH

FIGURE 3-4. FLUIDIZED BED INCINERATOR

(d) Fixed hearth. Fixed hearth incinerators, versions of which are also called controlled air or starved air incinerators, are another major technology used for hazardous waste incineration. Fixed hearth incineration is a two-stage combustion process (see Figure 3-5). Waste is fed into the first stage, or primary chamber, and usually burned at less than stoichiometric conditions (less than the theoretically required amount of air). The resultant smoke and pyrolysis products, consisting primarily of volatile hydrocarbons and carbon monoxide, along with the normal products of combustion, pass to the secondary chamber. Here, additional air is usually injected to complete the combustion. This two-stage process generally yields low stack particulate and carbon monoxide (CO) emissions. The primary chamber combustion reactions and combustion gas volumes are maintained at low levels by the starved air conditions so that particulate entrainment and carryover are minimized.

(e) Air pollution controls. Following incineration of hazardous wastes, combustion gases are generally further treated in an air pollution control system. The presence of chlorine or other halogens in some waste requires a scrubbing or absorption step to remove hydrogen chloride (HCl) and other halo-acids from the combustion gases. Ash in the waste is not destroyed in the combustion process. Depending on its composition, ash will exit either as bottom ash, at the discharge end of a kiln or hearth for example, or as particulate matter (fly ash) suspended in the combustion gas stream. Particulate emissions from most hazardous waste combustion systems generally have particle diameters of

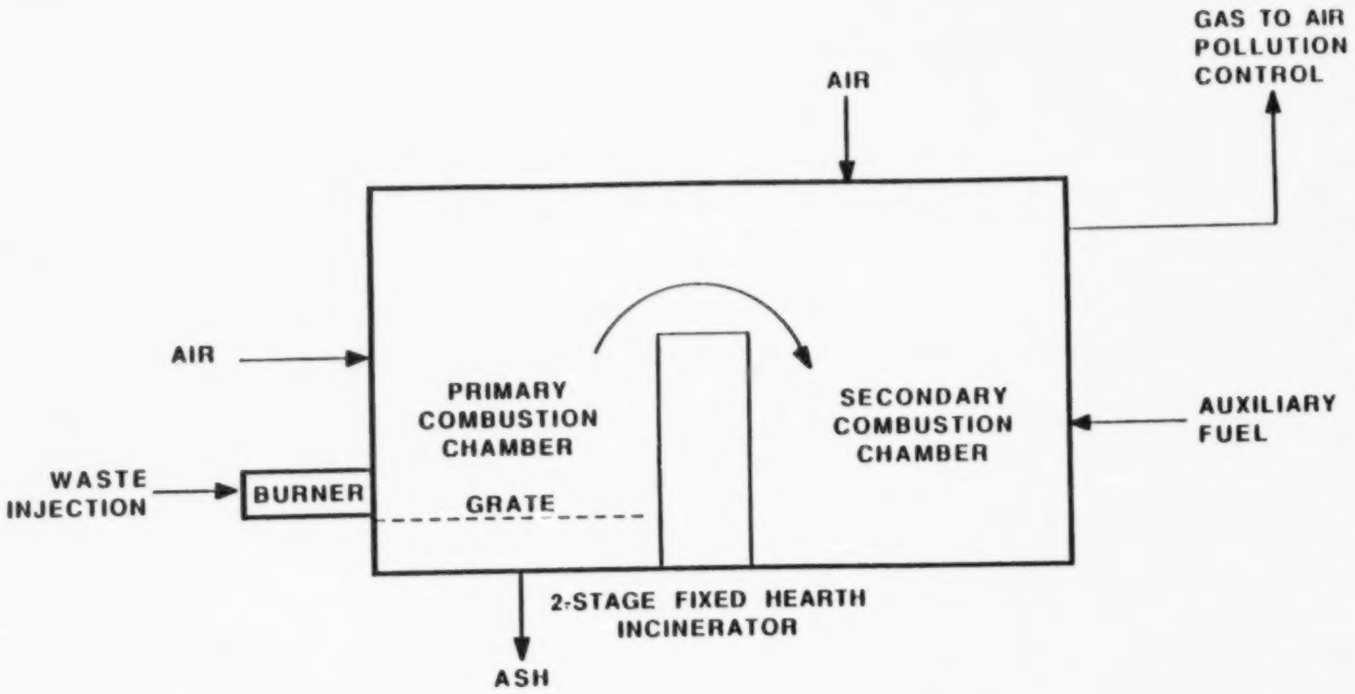

GAS TO AIR
POLLUTION
CONTROL
AIR
AIR
PRIMARY
COMBUSTION
CHAMBER
SECONDARY
COMBUSTION
CHAMBER
AUXILIARY
FUEL
WASTE
INJECTION
BURNER
GRATE
2-STAGE FIXED HEARTH
INCINERATOR
ASH

FIGURE 3-5. FIXED HEARTH INCINERATOR

less than 1 micron and require high-efficiency collection devices to minimize air emissions. In addition, scrubber systems provide an additional buffer against accidental releases of incompletely destroyed waste products resulting from poor combustion efficiency or combustion upsets.

(4) Waste characteristics affecting performance (WCAPs)

(a) Liquid injection. In determining whether liquid injection will achieve the same level of performance on an untested waste as on a previously tested waste, and whether performance levels can be transferred, EPA examines the bond dissociation energies of the constituents in the untested and tested wastes. This parameter is being used as a surrogate indicator of activation energy which, as discussed previously, destabilizes molecular bonds. In theory, the bond dissociation energy would be equal to the activation energy; however, in practice this is not always the case. Other energy effects (e.g., vibrational effects, the formation of intermediates, and interactions between different molecular bonds) may have a significant influence on activation energy.

Because of the shortcomings of bond energy calculations in estimating activation energy, EPA analyzed other waste characteristic parameters to determine whether these parameters would provide a better basis for transferring treatment standards from an untested waste to a tested waste. These parameters include heat of combustion, heat of formation, use of available kinetic data to predict activation energies, and general structural class. All of these parameters were rejected for the reasons provided below.

The heat of combustion measures only the difference in energy of the products and reactants; it does not provide information on the transition state (i.e., the energy input needed to initiate the reaction). Heat of formation is used as a tool to predict whether reactions are likely to proceed; however, there are a significant number of hazardous constituents for which these data are not available. The use of kinetic data was rejected because these data are limited and could not be used to calculate dissociation requirements for the wide range of hazardous constituents. Finally, EPA decided not to use structural classes because the Agency believes that evaluation of bond dissociation energies allows for a more direct determination of whether a constituent will be destabilized.

(b) Rotary kiln/fluidized bed/fixed hearth. Unlike liquid injection, these incineration technologies always generate a residual ash. Accordingly, in determining whether these technologies will achieve the same level of performance on an untested waste as on a previously tested waste and whether performance levels can be transferred, EPA examines the following waste characteristics that affect volatilization of organics from the waste, as well as destruction of the organics once volatilized. Relative to volatilization, EPA examines the thermal conductivity of the entire waste and the boiling points of the various constituents. As with liquid injection, EPA examines bond energies in determining whether treatment standards for scrubber water residuals can be transferred from a tested waste to an untested waste. Below is a discussion of how EPA arrived at thermal conductivity and boiling point as the best means to assess volatilization of organics from the waste; the discussion relative to bond energies is the same for these technologies as for liquid injection and is therefore not repeated.

(i) *Thermal conductivity*. Consistent with the underlying principles of incineration, a major factor with regard to whether a particular constituent will volatilize is the transfer of heat through the waste. In the case of rotary kiln, fluidized bed, and fixed hearth incineration, heat is transferred through the waste by three mechanisms: radiation, convection, and conduction. For a given incinerator, heat transferred through various wastes by radiation is more a function of the design and type of incinerator than of the waste being treated. Accordingly, the type of waste treated has a minimal impact on the amount of heat transferred by radiation. With regard to convection, EPA also believes that the type of heat transfer is generally more a function of the type and design of incinerator than of the waste itself. However, EPA is examining particle size as a waste characteristic that may significantly impact the amount of heat transferred to a waste by convection and thus may impact volatilization of the various organic compounds. The final type of heat transfer, conduction, is the one that EPA believes has the greatest impact on volatilization of organic

constituents. To measure this characteristic, EPA uses thermal conductivity; an explanation of this parameter, as well as how it can be measured, is provided below.

Heat flow by conduction is proportional to the temperature gradient across the material. The proportionality constant is a property of the material and is referred to as the thermal conductivity. (Note: The analytical method that EPA has identified for measurement of thermal conductivity is described in Appendix C.) In theory, thermal conductivity would always provide a good indication of whether a constituent in an untested waste would be treated to the same extent in the primary incinerator chamber as the same constituent in a previously tested waste.

In practice, thermal conductivity has some limitations in assessing the transferability of treatment standards; however, EPA has not identified a parameter that can provide a better indication of heat transfer characteristics of a waste. Below is a discussion of the limitations associated with thermal conductivity, as well as other parameters considered.

Thermal conductivity measurements, as part of a treatability comparison of two different wastes to be treated by a single incinerator, are most meaningful when applied to wastes that are homogeneous (i.e., uniform throughout). As wastes exhibit greater degrees of nonhomogeneity (e.g., significant concentration of metals in soil), thermal conductivity becomes less accurate in predicting treatability because the measurement essentially reflects heat flow through regions having the greatest conductivity (i.e., the path of least resistance) and not heat flow through all parts of the waste.

Btu value, specific heat, and ash content were also considered for predicting heat transfer characteristics. These parameters can no better account for nonhomogeneity than can thermal conductivity; additionally, they are not directly related to heat transfer characteristics. Therefore, these parameters do not provide a better indication of the heat transfer that will occur in any specific waste.

(ii) *Boiling point*. Once heat is transferred to a constituent within a waste, removal of this constituent from the waste depends on its volatility. As a surrogate for volatility, EPA is using the boiling point of the constituent. Compounds with lower boiling points have higher vapor pressures and, therefore, would be more likely to volatilize. The Agency recognizes that this parameter does not take into consideration the impact of other compounds in the waste on the boiling point of a constituent in a mixture; however, the Agency is not aware of a better measure of volatility that can easily be determined.

(5) Design and operating parameters

(a) Liquid injection. For a liquid injection unit, EPA's analysis of whether the unit is well designed focuses on both the likelihood that sufficient energy is provided to the waste to overcome the activation level for breaking molecular bonds and whether sufficient oxygen is present to convert the waste constituents to carbon dioxide and water vapor. In assessing the effectiveness of the design and operation of a liquid injection unit, EPA examines the following parameters: (i) the temperature, (ii) the excess oxygen concentration, (iii) the carbon monoxide concentration, and (iv) the waste feed rate. Below is a discussion of why EPA believes that these parameters are important, as well as a discussion of how these parameters are monitored during operation.

It is important to point out, relative to the development of land disposal restriction standards, that since liquid injection generally does not produce bottom ash, EPA is concerned with these design parameters only when a quench water or scrubber water residual is generated from treatment of a particular waste. If treatment of a particular waste in a liquid injection unit would not generate a wastewater stream, then the Agency, for purposes of land disposal treatment standards, would be concerned only with the waste characteristics that affect selection of the unit, not with the above-mentioned design parameters.

(i) *Temperature*. Temperature provides an indirect measure of the energy available (i.e., Btu/hr) to overcome the activation energy of waste constituents. As the design temperature increases, it becomes more likely that the molecular bonds will be destabilized and the reaction completed.

The temperature is normally controlled automatically through the use of instrumentation that senses the temperature and automatically adjusts the amount of fuel and/or waste being fed. The temperature signal transmitted to the controller can be simultaneously transmitted to a recording device and thereby continuously recorded. To fully assess the operation of the unit, it is important to know not only the exact location in the incinerator at which the temperature is being monitored but also the location of the design temperature.

(ii) *Excess oxygen concentration*. It is important that the incinerator contain oxygen in excess of the stoichiometric amount necessary to convert the organic compounds to carbon dioxide and water vapor. If insufficient oxygen is present, then destabilized waste constituents could recombine to form the same or other BDAT list organic compounds and potentially cause the scrubber water to contain higher concentrations of BDAT list constituents than would be the case for a well-operated unit.

In practice, the amount of oxygen fed to the incinerator is controlled by continuous sampling and analysis of the stack gas. If the amount of oxygen drops below the design value, then the analyzer transmits a signal to the valve or damper controlling the air supply and thereby increases the flow of oxygen. The analyzer simultaneously transmits a signal to a recording device so that the amount of excess oxygen can be continuously recorded. Again, as with temperature, it is important to know the location from which the combustion gas is being sampled.

(iii) *Carbon monoxide concentration*. The carbon monoxide concentration is an important operating parameter because it provides an indication of the extent to which the waste organic constituents are being converted to carbon dioxide and water vapor. An increase in the carbon monoxide level indicates that greater amounts of organic waste constituents are unreacted or partially reacted. Increased carbon monoxide levels can result from insufficient oxygen, too much oxygen (causing cooling), insufficient turbulence in the combustion zone, or insufficient residence time of combustion gases.

(iv) *Waste feed rate*. It is important to monitor the waste feed rate because it is correlated to the residence time. The residence time is associated with a specific Btu energy value of the feed and a specific volume of combustion gas generated. Prior to incineration, the Btu value of the waste is determined through the use of a laboratory device known as a bomb calorimeter. The volume of combustion gas generated from the waste to be incinerated is determined from a waste analysis referred to as an ultimate analysis. This analysis determines the amount of elemental constituents present, which include carbon, hydrogen, sulfur, oxygen, nitrogen, and halogens. Using this analysis plus the total amount of air added, the volume of combustion gas can be calculated. After both the Btu content and the expected combustion gas volume have been determined, the feed rate can be fixed at the desired combustion gas residence time. Continuous monitoring of the feed rate determines whether the unit was operated at a rate corresponding to the designed residence time.

(b) Rotary kiln. For this incineration technology, EPA examines both the primary and secondary chamber in evaluating the design of a particular incinerator. Relative to the primary chamber, EPA's assessment of design focuses on whether it is likely that enough energy is provided to the waste to volatilize the waste constituents. For the secondary chamber, analogous to the sole liquid injection incineration chamber, EPA examines the same parameters discussed previously under liquid injection incineration. (These parameters will not be discussed again here.)

In assessing the effectiveness of the design and operation of the primary chamber, EPA examines the following parameters: (i) the kiln temperature, (ii) the residence time of the waste solids, and (iii) the revolutions per minute. Below is a discussion of why EPA believes that these parameters are important, as well as a discussion of how these parameters are monitored during operation.

(i) Temperature. The primary chamber temperature is important because it provides an indirect measure of the energy input (i.e., Btu/hr) available for heating the waste. The higher the design temperature in a given kiln, the more likely it is that the constituents will volatilize. As discussed earlier in Section 3.3.4(5)(a), Liquid Injection, temperature should be continuously monitored and recorded. Additionally, it is important to know the location of the temperature sensing device in the kiln.

(ii) Residence time of the waste solids. This parameter is important in that it affects whether sufficient heat is transferred to a particular constituent for volatilization to occur. As the time that the waste in the kiln is increased, a greater quantity of heat is transferred to the hazardous waste constituents. The residence time is a function of the specific configuration of the rotary kiln, including the length and diameter of the kiln, the waste feed rate, and the rate of rotation.

(iii) Revolutions per minute (RPM). This parameter provides an indication of the turbulence that occurs in the primary chamber of a rotary kiln. As the turbulence increases, the quantity of heat transferred to the waste would also be expected to increase. However, as the RPM value increases, the residence time of waste solids decreases, resulting in a reduction of the quantity of heat transferred to the waste. This parameter needs to be carefully evaluated because it provides a balance between turbulence and residence time.

(c) Fluidized bed. As discussed previously in Section 3.3.4(2), Underlying Principles of Operation, the primary chamber accounts for almost all of the conversion of organic wastes to carbon dioxide and water vapor (and acid gas if halogens are present). The freeboard volume will generally provide additional residence time for combustion gases for thermal oxidation of the waste constituents. Relative to the primary chamber, the parameters that EPA examines in assessing the effectiveness of the design are temperature, residence time, and bed pressure differential. The first two were included in the rotary kiln discussion and will not be discussed here. The last, bed pressure differential, is important in that it provides an indication of the amount of turbulence and, therefore, indirectly the amount of heat supplied to the waste. In general, as the pressure drop increases, both the turbulence and heat supplied increase. The pressure drop through the bed should be continuously monitored and recorded to ensure that the designed valued is achieved.

(d) Fixed hearth. The design considerations for this incineration unit are similar to those for a rotary kiln with the exception that rate of rotation (i.e., RPM) is not an applicable design parameter. For the primary chamber of this unit, the parameters that EPA examines in assessing how well the unit is designed are the same as those discussed under Rotary kiln (Section 3.3.4(5)(b)); for the secondary chamber (i.e., afterburner), the design and operating parameters of concern are the same as those discussed under Liquid Injection (Section 3.3.4(5)(a)).

3.4 Descriptions of BDAT List Metals Treatment Technologies

3.4.1 Hexavalent Chromium Reduction

(1) Applicability. Hexavalent chromium reduction is a treatment technology applicable to wastes containing hexavalent chromium wastes, including plating solutions, stainless steel acid baths and rinses, "chrome conversion" coating process rinses, and chromium pigment manufacturing wastes. Because this technology requires that the pH be in

the acidic range, it would not be applicable to a waste that contains significant amounts of cyanide or sulfide. In such cases, lowering of the pH can result in the release of toxic gases such as hydrogen cyanide or hydrogen sulfide. It is important to note that additional precipitation treatment is required to remove trivalent chromium from the solution following reduction of the hexavalent chromium.

(2) Underlying principles of operation. The basic principle of hexavalent chromium reduction is to reduce the valence of chromium in solution (in the form of chromate or dichromate ions) from the hexavalent state to the trivalent state. "Reducing agents" used to effect the reduction include sodium sulfite ($Na_2S_2O_3$), sodium bisulfite ($NaHSO_3$), sodium metabisulfite ($Na_2S_2O_5$), sulfur dioxide (SO_2), sodium hydrosulfide (NaHS), and the ferrous form of iron (Fe^{+2}).

A typical reduction reaction, using sodium sulfite as the reducing agent, is as follows:

$$H_2(Cr^{+6})_2O_7 + 3Na_2SO_3 + 3H_2SO_4 \rightarrow (Cr^{+3})_2(SO_4)_3 + 3Na_2SO_4 + 4H_2O$$

The reaction is usually accomplished at pH values from 2 to 3.

At the completion of the chromium reduction step, the trivalent chromium compounds are precipitated from solution by raising the pH above 8. The insoluble trivalent chromium (in the form of chromium hydroxide) is then allowed to settle from solution. The precipitation reaction is as follows:

$$Cr_2(SO_4)_3 + 3Ca(OH)_2 \rightarrow 2Cr(OH)_3 + 3CaSO_4$$

(3) Description of chromium reduction process. The chromium reduction treatment process can be operated in a batch or continuous mode. A batch system consists of a reaction tank, a mixer to homogenize the contents of the tank, a supply of reducing agent, and a source of acid and base for pH control.

A continuous chromium reduction treatment system, as shown in Figure 3-6, usually includes a holding tank upstream of the reaction tank for flow and concentration equalization. It also includes instrumentation to automatically control the amount of reducing agent added and the pH of the reaction tank. The amount of reducing agent is controlled by the use of a sensor called an oxidation reduction potential (ORP) cell. The ORP sensor electronically measures, in millivolts, the level to which the redox reaction has proceeded at any given time. It must be noted, however, that the ORP reading is very pH dependent. Consequently, if the pH is not maintained at a steady value, the ORP will vary somewhat, regardless of the level of chromate reduction. Following chromium reduction, the trivalent chromium is precipitated and settled out of the solution, which is further treated and/or disposed of. Precipitated trivalent chromium is either reused or further treated by stabilization and land disposed.

(4) Waste characteristics affecting performance (WCAPs). In determining whether hexavalent chromium reduction will achieve the same level of performance on an untested waste as on a previously tested waste and whether performance levels can be transferred, EPA examines the

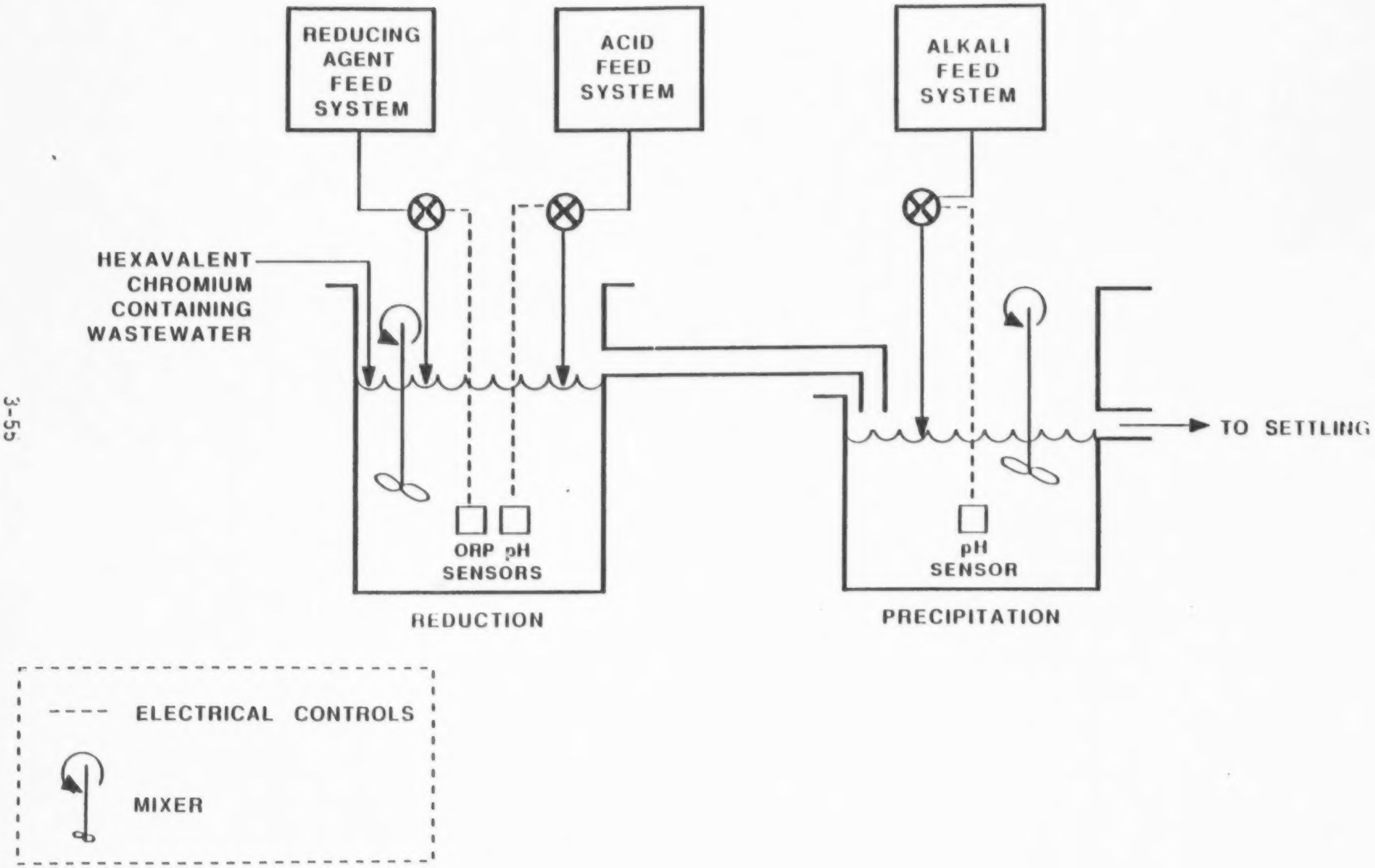

REDUCING AGENT FEED SYSTEM
ACID FEED SYSTEM
ALKALI FEED SYSTEM
HEXAVALENT CHROMIUM CONTAINING WASTEWATER
ORP pH SENSORS
REDUCTION
pH SENSOR
PRECIPITATION
TO SETTLING
---- ELECTRICAL CONTROLS
MIXER

FIGURE 3-6. CONTINUOUS HEXAVALENT CHROMIUM REDUCTION SYSTEM

following waste characteristics: (a) the concentration of oil and grease and (b) the concentration of other reducible metals.

(a) Concentration of oil and grease. EPA believes that oil and grease compounds could cause monitoring problems because of fouling of instrumentation (e.g., electrodes for pH and ORP sensors). If the concentration of oil and grease in the untested waste is significantly higher than that in the tested waste, the system may not achieve the same performance and other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(b) Concentration of other reducible metals. Ionized metals (such as silver, copper, and mercury) can compete with chromium for reducing agents, thereby requiring greater amounts of reducing agents to completely reduce the chromium. If the concentration of reducible metals in the untested waste is significantly higher than that in the tested waste, the system may not achieve the same performance. Additional reducing agents may be required to reduce the chromium and achieve the same treatment performance, or other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(5) Design and operating parameters. In assessing the effectiveness of the design and operation of a hexavalent chromium reduction system, EPA examines the following parameters: (a) the amount and type of reducing agent, (b) the pH, (c) the residence time, and (d) the degree of mixing.

(a) Amount and type of reducing agent. The choice of a reducing agent establishes the chemical reaction upon which the chromium reduction system is based. The amount of the reducing agent must be monitored and controlled in both batch and continuous systems to ensure complete reduction. In batch systems, the reducing agent is usually controlled by analysis of the hexavalent chromium remaining in solution, but it may also be controlled by using an ORP monitoring system. For continuous systems, the ORP reading is used to monitor and control the addition of the reducing agent.

The ORP will slowly change until the reduction reaction is completed, at which point the ORP will change rapidly. The set point for the ORP monitor is approximately the reading just after the rapid change has begun. The reduction system must then be monitored periodically to determine whether the selected set point needs further adjustment. EPA monitors the hexavalent chromium remaining in solution for batch systems and monitors the ORP continuously, if possible, for continuous systems to ensure that an effective amount of the reducing agent has been added to the system.

(b) pH. For batch and continuous systems, pH affects the reduction reaction. The reaction speed is significantly reduced at pH values above approximately 4.0. For a batch system, the pH can be monitored intermittently during treatment. For a continuous system, the pH must be monitored continuously because of its effect on the ORP reading. EPA monitors the pH to ensure that the system is operating at the appropriate design condition and to diagnose operational problems.

(c) Residence time. The residence time impacts the extent to which the hexavalent chromium reduction reaction goes to completion. For batch systems, the residence time is controlled directly by adjusting the treatment time in the reaction tank. For continuous systems, the feed rate is controlled to make sure that the system is operated at the appropriate design residence time. EPA monitors the residence time to ensure that sufficient time is provided to effectively reduce the waste.

(d) Degree of mixing. The reduction system should be designed to provide adequate mixing in order to ensure uniform distribution of the reducing agent and chromium throughout the reactor. The quantifiable degree of mixing is a complex assessment that includes, among other things, the amount of energy supplied, the length of time the material is mixed, and the related turbulence effects of the specific size and shape of the reaction vessel. This is beyond the scope of simple measurement. EPA, however, evaluates the degree of mixing qualitatively by considering whether mixing is provided and whether the type of mixing device is one that could be expected to achieve uniform mixing of the waste.

3.4.2 Chemical Precipitation

(1) Applicability. Chemical precipitation is a treatment technology applicable to wastewaters containing a wide range of dissolved and other metals, as well as other inorganic substances such as fluorides. This technology removes these metals and inorganics from solution in the form of insoluble solid precipitates. The solids formed are then separated from the wastewater by settling, clarification, and/or polishing filtration.

For some wastewaters, such as chromium plating baths or plating baths containing cyanides, the metals exist in solution in a very soluble form. This solubility can be caused by the metal's oxidation state (for hexavalent chromium wastewaters) or by complexing of the metals (for high cyanide-containing wastewaters). In both cases, pretreatment, such as hexavalent chromium reduction or oxidation of the metal-cyanide complexes, may be required before the chemical precipitation process can be applied effectively.

(2) Underlying principles of operation. The basic principle of operation of chemical precipitation is that metals and inorganics in wastewater are removed by the addition of a precipitating agent that converts the soluble metals and inorganics to insoluble precipitates. These precipitates are settled, clarified, and/or filtered out of solution, leaving a lower concentration of metals and inorganics in the wastewater. The principal precipitation agents used to convert soluble metal and inorganic compounds to less soluble forms include: lime ($Ca(OH)_2$), caustic (NaOH), sodium sulfide (Na_2S), and, to a lesser extent, soda ash (Na_2CO_3), phosphate ($PO_4^{=}$), and ferrous sulfide (FeS).

The solubility of a particular compound depends on the extent to which the electrostatic forces holding the ions of the compound together can be overcome. The solubility changes significantly with temperature, with most metal compounds becoming more soluble as the temperature increases. Additionally, the solubility is affected by other constituents present in the wastewater, including other ions and complexing agents. Regarding specific ionic forms, nitrates, chlorides, and sulfates are, in general, more soluble than hydroxides, sulfides, carbonates, and phosphates.

Once the soluble metal and inorganic compounds have been converted to precipitates, the effectiveness of chemical precipitation is determined by how successfully they are physically removed. Removal usually relies on a settling process; that is, a particle of a specific size, shape, and composition will settle at a specific velocity, as described by Stokes' Law. For a batch system, Stokes' Law is a good predictor of settling time because the pertinent particle parameters essentially remain constant. In practice, however, settling time for a batch system is normally determined by empirical testing. For a continuous system, the theory of settling is complicated by such factors as turbulence, short-circuiting of the wastewater, and velocity gradients, thereby increasing the importance of empirical tests to accurately determine appropriate settling times.

(3) Description of chemical precipitation process. The equipment and instrumentation required for chemical precipitation vary depending on whether the system is batch or continuous. Both systems are discussed below.

For a batch system, chemical precipitation requires a feed system for the treatment chemicals and a reaction tank where the waste can be treated and allowed to settle. When lime is used, it is usually added to the reaction tank in a slurry form. The supernatant liquid is generally analyzed before discharge to ensure that settling of precipitates is adequate.

For a continuous system, additional tanks are necessary, as well as the instrumentation to ensure that the system is operating properly. A schematic of a continuous chemical precipitation system is shown in Figure 3-7. In this system, wastewater is fed into an equalization tank where it is mixed to provide more uniformity, thus minimizing the variability in the type and concentration of constituents sent to the reaction tank.

Following equalization, the wastewater is pumped to a reaction tank where precipitating agents are added. This is done automatically by using instrumentation that senses the pH of the system for hydroxide precipitating agents, or the oxidation-reduction potential (ORP) for non-hydroxide precipitating agents, and then pneumatically adjusts the position of the treatment chemical feed valve until the design pH or ORP value is achieved. (The pH and ORP values are affected by the concentration of hydroxide and nonhydroxide precipitating agents, respectively, and are thus used as indicators of their concentrations in the reaction tank.)

In the reaction tank, the wastewater and precipitating agents are mixed to ensure commingling of the metal and inorganic constituents to be removed and the precipitating agents. In addition, effective dispersion of the precipitating agents throughout the tank is necessary to properly monitor and thereby control the amount added.

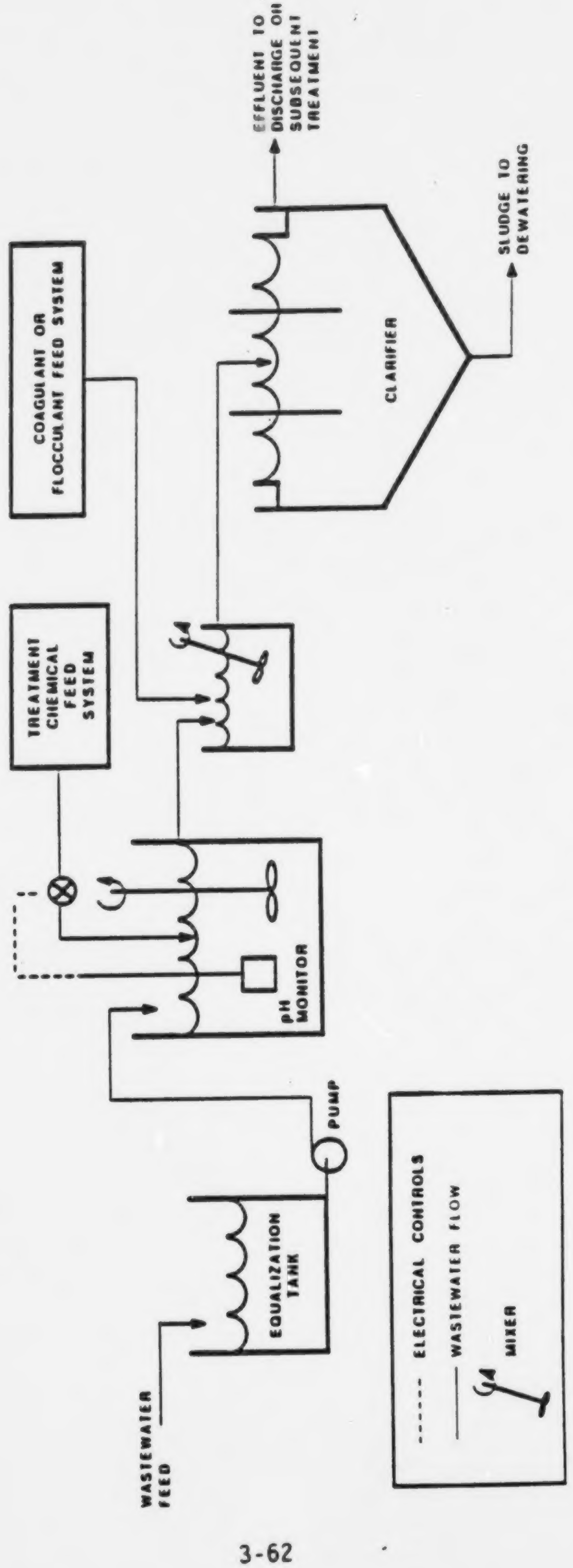

WASTEWATER FEED
EQUALIZATION TANK
PUMP
pH MONITOR
TREATMENT CHEMICAL FEED SYSTEM
COAGULANT OR FLOCCULANT FEED SYSTEM
CLARIFIER
EFFLUENT TO DISCHARGE OR SUBSEQUENT TREATMENT
SLUDGE TO DEWATERING
ELECTRICAL CONTROLS
WASTEWATER FLOW
MIXER

FIGURE 3-7. CONTINUOUS CHEMICAL PRECIPITATION

Following reaction of the wastewater with the stabilizing agents, coagulating or flocculating compounds are added to chemically assist the settling process. Coagulants and flocculants increase the particle size and density of the precipitated solids, both of which increase the rate of settling. The coagulant or flocculating agent that best improves settling characteristics varies depending on the particular precipitates to be settled.

Settling can be conducted in a large tank by relying solely on gravity or it can be mechanically assisted through the use of a circular clarifier or an inclined plate settler. Schematics of the two settling systems are shown in Figures 3-8 and 3-9. Following the addition of coagulating or flocculating agents, the wastewater is fed to a large settling tank, circular clarifier, or inclined plate settler where the precipitated solids are removed. These solids are generally further treated in a sludge filtration system to dewater them prior to disposal. This technology is discussed in Section 3.4.3 of this document.

The supernatant liquid effluent can be further treated in a polishing filtration system to remove precipitated residuals both in cases where the settling system is underdesigned and in cases where the particles are difficult to settle. Polishing filtration is discussed in Section 3.4.4 of this document.

(4) Waste characteristics affecting performance (WCAPs). In determining whether chemical precipitation will achieve the same level of performance on an untested waste as on a previously tested waste and whether performance levels can be transferred, EPA examines the

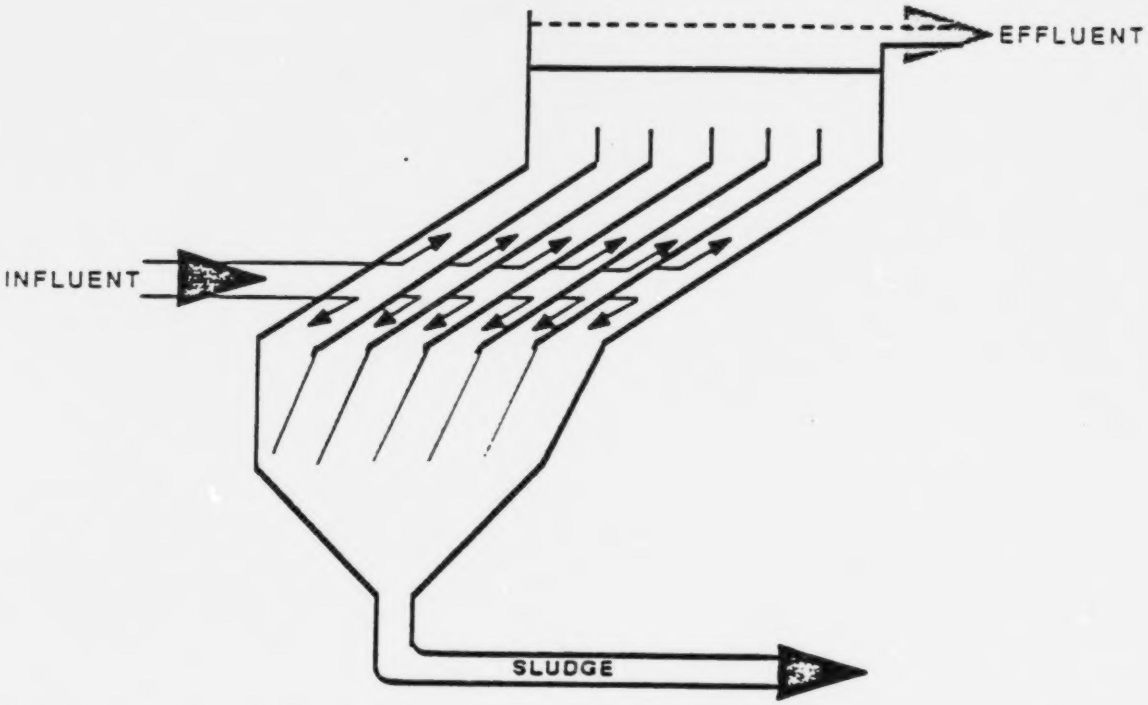
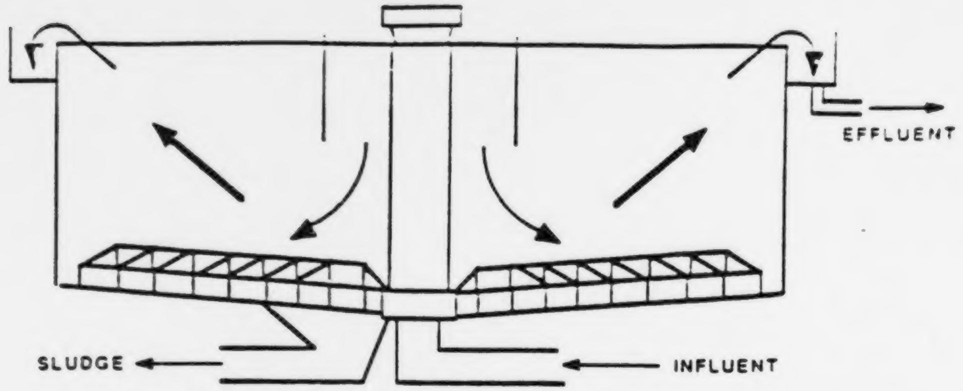
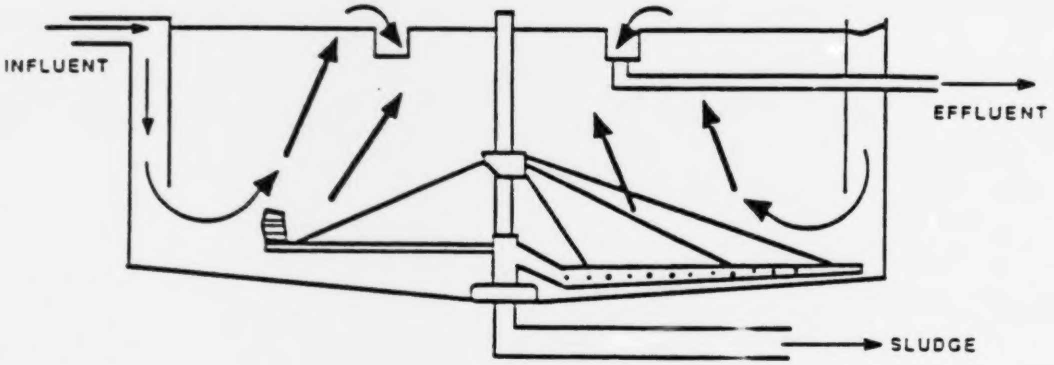

EFFLUENT
INFLUENT
SLUDGE

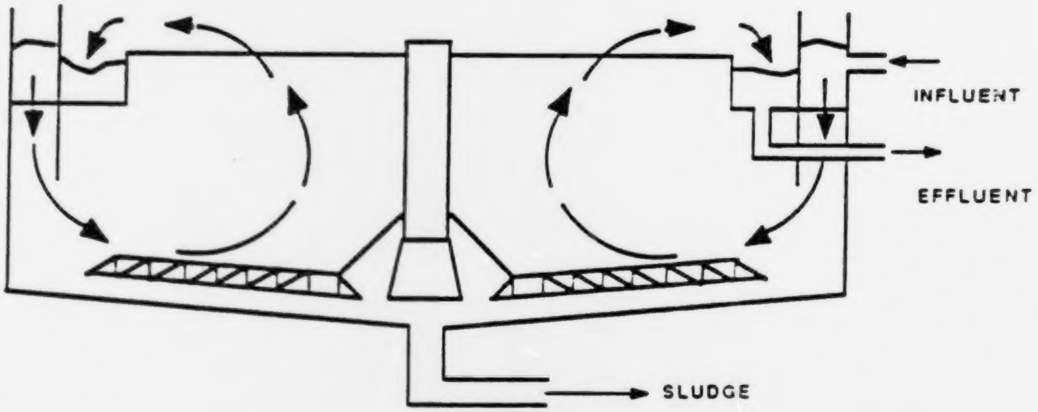
FIGURE 3-8. INCLINED PLATE SETTLER


EFFLUENT
SLUDGE
INFLUENT

CENTER FEED CLARIFIER WITH SCRAPER SLUDGE REMOVAL SYSTEM


INFLUENT
EFFLUENT
SLUDGE

RIM FEED - CENTER TAKEOFF CLARIFIER WITH HYDRAULIC SUCTION SLUDGE REMOVAL SYSTEM


INFLUENT
EFFLUENT
SLUDGE

RIM FEED - RIM TAKEOFF CLARIFIER

FIGURE 3-9. CIRCULAR CLARIFIERS

following waste characteristics: (a) the concentration and type of metals, (b) the concentration of total dissolved solids (TDS), (c) the concentration of complexing agents, and (d) the concentration of oil and grease.

(a) Concentration and type of metals. For most metals, there is a specific pH at which the metal precipitate is least soluble. As a result, when a waste contains a mixture of many metals, it is not possible to operate a treatment system at a single pH or ORP value that is optimal for the removal of all metals. The extent to which this affects treatment depends on the particular metals to be removed and their respective concentrations. One alternative is to operate multiple precipitations, with intermediate settling, when the optimum pH occurs at markedly different levels for the metals present. If the concentration and type of metals in an untested waste differ from and are significantly higher than those in the tested waste, the system may not achieve the same performance. Additional precipitating agents, alternate pH/ORP values, and/or multiple precipitations may be required to achieve the same treatment performance, or other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(b) Concentration of total dissolved solids (TDS). High concentrations of total dissolved solids can interfere with precipitation reactions, as well as inhibit settling. Poor precipitate formation and flocculation are results of high TDS concentrations, and higher concentrations of solids are found in the treated wastewater residuals. If the TDS concentration in an untested waste is significantly higher than that in the tested waste, the system may not achieve the same performance. Higher concentrations of precipitating agents may be required to achieve the same treatment performance, or other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(c) Concentration of complexing agents. A metal complex consists of a metal ion surrounded by a group of other inorganic or organic ions or molecules (often called ligands). In the complexed form, metals have a greater solubility. Also, complexed metals inhibit the reaction of the metal with the precipitating agents and therefore may not be removed as effectively from solution by chemical precipitation. However, EPA does not have analytical methods to determine the concentration of complexed metals in wastewaters. The Agency believes that the best indicator for complexed metals is to analyze for complexing agents, such as cyanide, chlorides, EDTA, ammonia, amines, and methanol, for which analytical methods are available. Therefore, EPA uses the concentration of complexing agents as a surrogate waste characteristic for the concentration of metal complexes. If the concentration of complexing agents in an untested waste is significantly higher than that in the tested waste, the system may not achieve the same performance. Higher concentrations of precipitating agents may be required to achieve the same treatment performance, or other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(d) Concentration of oil and grease. The concentration of oil and grease in a waste inhibits the settling of the precipitate by creating emulsions that require a long settling time. Suspended oil droplets in water tend to suspend particles such as chemical precipitates, which would otherwise settle out of solution. Even with the use of coagulants or flocculants, the settling of the precipitate is less effective. If the concentration of oil and grease in an untested waste is significantly higher than that in the tested waste, the system may not achieve the same performance. Pretreatment of the waste may be required to reduce the oil and grease concentration and achieve the same treatment performance. or other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(5) Design and operating parameters. In assessing the effectiveness of the design and operation of a chemical precipitation system, EPA examines the following parameters: (a) the pH/ORP value; (b) the precipitation temperature; (c) the residence time; (d) the amount and type of precipitating agents, coagulants, and flocculants; (e) the degree of mixing; and (f) the settling time.

(a) pH/ORP value. The pH/ORP value in continuous chemical precipitation systems is used as an indicator of the concentration of precipitating agents in the reaction tank and, thus. to regulate their addition to the tank. The pH/ORP value also affects the solubility of metal precipitates formed and therefore directly impacts the effectiveness of their removal. EPA monitors the pH/ORP value continuously, if possible, to ensure that the system is operating at the appropriate design condition and to diagnose operational problems.

(b) Precipitation temperature. The precipitation temperature affects the solubility of the metal precipitates. Generally, the lower the temperature, the lower the solubility of the metal precipitates and vice versa. EPA monitors the precipitation temperature continuously, if possible, to ensure that the system is operating at the appropriate design condition and to diagnose operational problems.

(c) Residence time. The residence time impacts the extent of the chemical reactions to form metal precipitates and, as a result, the amount of precipitates that can be settled out of solution. For batch systems, the residence time is controlled directly by adjusting the treatment time in the reaction tank. For continuous systems, the wastewater feed rate is controlled to make sure that the system is operating at the appropriate design residence time. EPA monitors the residence time to ensure that sufficient time is provided to effectively precipitate from the wastewater.

(d) Amount and type of precipitating agents, coagulants, and flocculants. The amount and type of precipitating agent used to effectively treat the wastewater depends on the amount and type of metal and inorganic constituents in the wastewater to be treated. Other design and operating parameters, such as the pH/ORP value, the precipitation temperature, the residence time, the amount and type of coagulants and flocculants, and the settling time, are determined by the selection of precipitating agents.

The addition of coagulants and flocculants improves the settling rate of the precipitated metals and inorganics and allows for smaller settling systems (i.e., lower settling time) to achieve the same degree of settling as a much larger system. Typically, anionic polyelectrolyte flocculating agents are most effective with metal precipitates, although cationic or nonionic polyelectrolytes also are effective. Typical doses range from 0.1 to 10 mg/l of the total influent wastewater stream. Conventional coagulants, such as alum (aluminum sulfate) and iron chlorides or sulfates, are also effective, but must be dosed at much higher concentrations to achieve the same result. Therefore, these coagulants add more to the settled sludge volume requiring disposal than do the polyelectrolyte flocculants. EPA examines the amount and type of precipitating agents, coagulants, and flocculants added, and their method of addition to the wastewater, to ensure effective precipitation.

(e) Degree of mixing. Mixing provides greater uniformity of the wastewater feed and disperses precipitating agents, coagulants, and flocculants throughout the wastewater to ensure the most rapid precipitation reactions and settling of precipitate solids possible. The quantifiable degree of mixing is a complex assessment that includes, among other things, the amount of energy supplied, the length of time the material is mixed, and the related turbulence effects of the specific size and shape of the tank. This is beyond the scope of simple measurement. EPA, however, evaluates the degree of mixing qualitatively by considering whether mixing is provided and whether the type of mixing device is one that could be expected to achieve uniform mixing of the wastewater.

(f) Settling time. Adequate settling time must be provided to make sure that removal of the precipitated solids from the wastewater has been completed. EPA monitors the settling time to ensure effective solids removal.

3.4.3 Sludge Filtration

(1) Applicability. Sludge filtration, also known as sludge dewatering or cake-formation filtration, is a technology used on wastes that contain high concentrations of suspended solids, generally higher than 1 percent (10,000 mg/l). Sludge filtration is commonly applied to waste sludges, such as clarifier solids, for dewatering. These sludges can be dewatered to 20 to 50 percent solids concentration using this technology.

(2) Underlying principles of operation. The basic principle of operation for sludge filtration is the separation of particles from a mixture of fluid and particles by a medium that permits the flow of the fluid but retains the particles. The larger the particles, the easier they are to separate from the fluid.

Extremely small particles, in the colloidal range, may not be filtered effectively in a sludge filtration system and may appear in the filtrate. To mitigate this problem, the waste can be treated prior to filtration to modify the particle size distribution in favor of the larger particles by using appropriate precipitants, coagulants, flocculants, and filter aids. The selection of the appropriate precipitant and coagulant is important because they affect the type of waste particles formed. For example, lime precipitation usually produces larger, less gelatinous particles (which are easier to separate from waste sludges using this technology) than caustic soda precipitation. For particles that become too small to filter effectively because of poor resistance to shearing, the use of coagulants and flocculants improves shear resistance in addition to increasing the size of the particles. Also, if pumps are used, shear can be minimized by lowering the pump speed or using a low-shear type of pump. Filter aids such as diatomaceous earth are used to precoat cloth-type filter media and provide an initial filter cake onto which additional solids can be deposited during the filtration process. The presence of the precoat aids in the removal of small particles from the waste being filtered. These particles adhere to the precoat solids during the filtration process.

(3) Description of sludge filtration process. For sludge filtration, waste is pumped through a cloth-type filter medium (also known as pressure filtration, such as that performed with a plate and frame filter), drawn by vacuum through the cloth medium (also known as vacuum filtration, such as that performed with a vacuum drum filter), or

gravity-drained and mechanically pressured through two continuous fabric belts (also known as belt filtration, such as that performed with a belt filter press). In all cases, the solids "cake" builds up on the filter medium and acts as a filter for subsequent solids removal. For a plate and frame type filter, removal of the solids is accomplished by taking the unit off-line, opening the filter, and using an adjustable knife mechanism to scrape the solids off (a batch process). For the vacuum filter, cake is removed continuously by using an adjustable knife mechanism to scrape the sludge from the vacuum drum as the drum rotates. For the belt filter, the cake is continuously removed by a discharge roller and blade, which dislodge the cake from the belt. For a specific sludge, the plate and frame type filter will usually produce the driest cake (highest percentage of solids). The belt filter produces a drier cake than a vacuum filter, but not as dry as that produced by a plate and frame filter.

(4) Waste characteristics affecting performance (WCAPs). In determining whether sludge filtration will achieve the same level of performance on an untested waste as on a previously tested waste and whether performance levels can be transferred, EPA examines the following waste characteristics: (a) the solid waste particle size and (b) the type of solid waste particles.

(a) Solid waste particle size. The smaller the particle size, the more the particles tend to go through the filter media. This is especially true for a vacuum filter. For a pressure filter (such as a plate and frame), smaller particles may require higher pressures for equivalent fluid throughput because the smaller pore spaces between particles collected on the filter medium create resistance to flow. If the solid waste particle size distribution of an untested waste is significantly lower than that of the tested waste, the system may not achieve the same performance. Pretreatment of the waste with coagulants and flocculants may be required to increase the particle sizes and achieve the same treatment performance, or other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(b) Type of solid waste particles. Some solids formed during metal precipitation are gelatinous in nature and cannot be dewatered well by sludge filtration. In fact, for vacuum filtration a cake may not form at all. In most cases, solids can be made less gelatinous by use of the appropriate coagulants and coagulant dosage prior to settling/clarification or after settling/ clarification but prior to filtration. In addition, the use of lime instead of caustic in chemical precipitation of metals reduces the formation of gelatinous solids. Also, adding filter aids, such as lime or diatomaceous earth, to a gelatinous sludge increases its filterability significantly. Finally, precoating the filter with diatomaceous earth prior to sludge filtration assists in dewatering gelatinous sludges. If an untested waste is significantly more gelatinous than the tested waste, the system may not achieve the same performance. Pretreatment of the waste with coagulants and filter aids or precoating of the filter may be required to decrease the gelatinous nature of the waste and achieve the same treatment performance, or other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(5) Design and operating parameters. In assessing the effectiveness of the design and operation of a sludge filtration system, EPA examines the following parameters: (a) the type and size of filter; (b) the filtration pressure; (c) the amount and type of coagulants, flocculants, and filter aids used; and (d) the hydraulic loading rate.

(a) Type and size of filter. The type and size of the filtration system used is dependent on the nature of the particles to be separated, the desired solids concentration in the cake, the amount and concentration of solids in the feed, and the required downtime for solids removal and maintenance. Typically, a pressure-type filter (such as a plate and frame) will yield a drier cake than a belt or vacuum type filter and will also be more tolerant of variations in influent sludge characteristics. Pressure-type filters, however, are batch processes. When cake is built up to the maximum depth physically possible (constrained by filter geometry) or to the maximum design pressure, the filtration system is taken off-line while the cake is removed. (An alternate unit can be put on-line while the other is being cleaned.) Belt and vacuum type filters are continuous systems (i.e., cake discharges continuously), but each of these filters is usually much larger than a pressure filter with the same capacity.

For all filter types, the larger the filter, the greater its hydraulic capacity (overall throughput) and, for pressure-type filters, the longer the filter runs between cake discharges. EPA examines the type and size of the filter chosen to ensure that it is capable of achieving effective dewatering and filtration of the waste sludge.

(b) Filtration pressure. Pressure impacts both the design pore size of the filter media and the design feed flow rate. For plate and frame filters, the higher the feed pressure, the drier the cake will be and the longer the runs will be prior to cake discharge. However, for gelatinous solids, such as some metal hydroxides, excessive pressures may cause the solids to clog the filter pores and prevent additional sludge filtration. Also, high pressures may force particles through the filter medium, resulting in ineffective filtration. For vacuum filters, the maximum amount of vacuum typically applied ranges from 20 to 25 inches of mercury. (The absolute maximum amount of vacuum that can be applied is 29.9 inches of mercury, or atmospheric pressure.) For belt filters, neither pressure nor vacuum is applied to the waste feed (although mechanical pressure is applied). For plate and frame and vacuum-type filtration systems, EPA monitors the filtration pressure (or vacuum) applied to the waste feed continuously, if possible, to ensure that the system is operating at the appropriate design conditions and to diagnose operational problems.

(c) Amount and type of coagulants, flocculants, and filter aids. Coagulants, flocculants, and filter aids may be mixed with the waste feed prior to filtration. Coagulants and flocculants affect the type and size of waste particles in the waste and, hence, their ease of removal. Their effect is particularly significant for vacuum filtration since they may make the difference between no cake and the formation of a relatively dry cake. In a pressure filter, coagulants, flocculants, and filter aids significantly improve overall throughput and cake dryness. Filter aids, such as diatomaceous earth, can be precoated on all filters for particularly difficult-to-filter sludges (those containing a high concentration of gelatinous solids). The precoat layer acts somewhat like a filter in that sludge solids are trapped in the precoat pore spaces. Coagulants, flocculants, and filter aids are particularly useful when the sludge has a high percentage of very small particles and/or when the concentration of solids in the waste feed is low. Inorganic coagulants include alum, ferric sulfate, and lime. Organic flocculants are polyelectrolytes. Diatomaceous earth is the most commonly used filter aid. The use of coagulants, flocculants, and filter aids significantly increases the amount of solids in the sludge requiring disposal, although polyelectrolyte flocculant usage usually does not increase sludge volume significantly because the required dosage is relatively low. If the addition of coagulants, flocculants, and filter aids is required, EPA examines the amount and type added to the waste sludge, along with their method of addition, to ensure effective dewatering and filtration.

(d) Hydraulic loading rate. Lower hydraulic loading rates generally improve filtration performance. Higner hydraulic loading rates yield greater overall throughput, but result in the formation of wetter cakes (lower percent solids) and, for plate and frame filters, shorter cycle times. EPA monitors the hydraulic loading rate to ensure effective dewatering and filtration of the waste sludge.

3.4.4 Polishing Filtration

(1) Applicability. Polishing filtration is a treatment technology applicable to wastewaters containing relatively low concentrations of solids (less than 1,000 mg/l). This type of filtration is typically used as a polishing step for the supernatant liquid following chemical precipitation and settling/clarification of wastewaters containing metal and other inorganic precipitates. Polishing filtration removes particles that are difficult to settle because of their shape and/or density, as well as precipitated particles from an underdesigned settling system.

(2) Underlying principles of operation. The basic principle of operation for polishing filtration is the removal of particles from a mixture of fluid and particles by a medium that permits the flow of the fluid but retains the particles. The larger the particles, the easier they are to remove from the fluid.

Extremely small particles, in the colloidal range, may not be removed effectively in a polishing filtration system and thus may appear in the treated wastewater. To mitigate this problem, the wastewater can be treated prior to filtration to modify the particle size distribution in favor of the larger particles by using appropriate precipitants, coagulants, flocculants, and filter aids. The selection of the appropriate precipitant and coagulant is important because they affect the type of waste particles formed. For example, lime precipitation usually produces larger, less gelatinous particles (which are easier to remove from aqueous wastes using this technology) than does caustic soda precipitation. For particles that become too small to remove effectively because of poor resistance to shearing, the use of coagulants and flocculants both improves shear resistance and increases the size of the particles. Also, if pumps are used, shear can be minimized by lowering the pump speed or using a low-shear type of pump. Filter aids such as diatomaceous earth are used to precoat cloth-type filter media and to provide an initial filter cake onto which additional solids can be deposited during the filtration process. The presence of the precoat aids in the removal of small particles from the solution being filtered. These particles adhere to the precoat solids during the filtration process.

(3) Description of polishing filtration processes. During polishing filtration, wastewater may flow by gravity or under pressure to the filter. The two most common polishing filtration processes are cartridge and granular bed filtration. Both processes remove particles that are much smaller than the pore size of the filter media by straining,

adsorption, and coagulation/flocculation mechanisms; they are also capable of producing an effluent with a low level of solids (less than 10 mg/l).

(a) Cartridge filtration. Cartridge filters can be used for relatively low waste feed flows. In this process, a cylindrically shaped cartridge with a matted cloth-type filter medium is placed within a sealed vessel. Wastewater is pumped through the cartridge until the flow drops excessively or until the pumping pressure becomes too high because of plugging of the filter media. The sealed vessel is then opened, and the plugged cartridge is removed and replaced with a new cartridge. The plugged cartridge is then disposed of. Cartridge filters may be assembled in a parallel arrangement to increase the overall system flow.

(b) Granular bed filtration. For relatively large volume flows, granulated media such as sand or anthracite coal are used singly or in combination to trap suspended solids within the pore spaces of the media. Dual and multimedia filter arrangements allow higher flow rates and efficiencies. Typical hydraulic loading rates range from 2 to 5 gal/ft^2-min for single-medium filters and from 4 to 8 gal/ft^2-min for multimedia filters.

In this process, wastewater is either gravity fed or pumped through the granular bed media and filtered until either the flow drops excessively or the pumping pressure becomes too high because of plugging of the filter media. Granular media filters are cleaned by backwashing with filtered water in an upflow manner to expand the bed, loosen the media granules, and resuspend the entrapped filtered solids. The backwash water, which may be as much as 10 percent of the volume of the filtered wastewater, is then returned to the wastewater treatment system so that the filtered solids in the backwash water can be settled out of solution prior to discharge.

(4) Waste characteristics affecting performance (WCAPs). In determining whether polishing filtration will achieve the same level of performance on an untested waste as on a previously tested waste and whether performance levels can be transferred, EPA examines the following waste characteristics: (a) the solid waste particle size and (b) the type of solid waste particles.

(a) Solid waste particle size. Extremely small particles, in the colloidal range, may not be filtered effectively in a polishing filter and thus may appear in the filtrate. If the solid waste particle size distribution of an untested waste is significantly lower than that of the tested waste, the system may not achieve the same performance. Pretreatment of the waste with coagulants and flocculants may be required to increase the particle sizes and achieve the same treatment performance, or other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(b) Type of solid waste particles. Some solids formed during metal precipitation are gelatinous in nature and are difficult to filter. In most cases, solids can be made less gelatinous by use of the appropriate coagulants and coagulant dosage prior to settling/clarification, or after settling/clarification but prior to filtration. In addition, the use of lime instead of caustic in chemical precipitation of metals reduces the formation of gelatinous solids. If solids in an untested waste are significantly more gelatinous than those in the tested waste, the system may not achieve the same performance. Pretreatment of the waste with coagulants may be required to decrease the gelatinous nature of the waste and achieve the same treatment performance, or other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(5) Design and operating parameters. In assessing the effectiveness of the design and operation of a polishing filtration system, EPA examines the following parameters: (a) the type and size of the filter; (b) the filtration pressure; (c) the amount and type of coagulants, flocculants, and filter aids used; (d) the hydraulic loading rate; and (e) the pore size of the filter media.

(a) Type and size of filter. The type and size of the polishing filtration system used is dependent on the nature of the particles to be removed, the desired solids concentration in the filtrate, and the amount and concentration of solids in the feed. As noted earlier, cartridge filtration is limited to lower volume wastewaters and/or those with lower solids concentrations than is granular bed filtration. For granular bed filtration, when more than one medium is used (dual and multimedia filter arrangements such as sand and anthracite coal), a higher capacity can be expected for the same size filter bed. For both filtration processes, the larger the filter size, the greater its hydraulic capacity (overall throughput) and the longer the filter runs between solids removal. EPA examines the type and size of the filter chosen to ensure that it is capable of achieving effective filtration of the wastewater.

(b) Filtration pressure. Pressure impacts both the design pore size of the filter media and the design feed flow rate (hydraulic loading rate). The higher the feed pressure, the longer the run will be prior to solids removal. For gelatinous solids, such as metal hydroxides, however, excessive pressure may cause the solids to clog the filter pores and prevent additional polishing filtration. Also, high pressures may force particles through the filter medium, resulting in ineffective filtration. EPA monitors the filtration pressure applied to the waste feed continuously, if possible, to ensure that the system is operating at the appropriate design condition and to diagnose operational problems.

(c) Amount and type of coagulants, flocculants, and filter aids. Coagulants, flocculants, and filter aids may be mixed with the wastewater prior to filtration. Coagulants and flocculants affect the type and size of waste particles in the wastewater and, hence, their ease of removal. Filter aids both improve the effectiveness of filtering gelatinous particles and increase the time that the filter can stay on-line by increasing the surface area available for filtration. Coagulants, flocculants, and filter aids are particularly useful when the wastewater contains a high percentage of very small particles and/or when the concentration of solids in the wastewater is low. Inorganic coagulants include alum, ferric sulfate, and lime; organic flocculants are polyelectrolytes. Diatomaceous earth is the most commonly used filter aid. The use of coagulants, flocculants, and filter aids significantly increases the amount of solids requiring removal and disposal. Polyelectrolyte flocculant usage, however, usually does not increase the solids volume significantly because the required dosage is relatively low. If the addition of coagulants, flocculants, and filter aids is required, EPA examines the amount and type added, as well as their method of addition to the wastewater, to ensure effective filtration.

(d) Hydraulic loading rate. Lower hydraulic loading rates generally improve filtration performance. Higher hydraulic loading rates yield greater throughput, but result in shorter cycle times. EPA monitors the hydraulic loading rate to ensure effective filtration of the wastewater.

(e) Pore size of the filter media. The pore size of the filter media determines the particle size that will be effectively removed from the wastewater. EPA examines the pore size of the filter media to ensure effective filtration of the wastewater.

3.4.5 Stabilization of Metals

(1) Applicability. Stabilization is a treatment technology applicable to wastes containing leachable metals and having a high filterable solids content, low total organic carbon (TOC) content, and low oil and grease content. This technology is commonly used to treat residuals generated from treatment of electroplating wastewaters and

incineration ash residues. For wastes with recoverable levels of metals, high temperature metals recovery and retorting technologies may be applicable.

Stabilization refers to a broad class of treatment processes that immobilize hazardous constituents in a waste. Solidification and fixation are other terms that are sometimes used synonymously for stabilization or to describe specific variations within the broader class of stabilization. Related technologies are encapsulation and thermoplastic binding. However, EPA considers these technologies to be distinct from stabilization in that their operational principles are significantly different.

(2) Underlying principles of operation. The basic principle of operation for stabilization is that leachable metals in a waste are immobilized following the addition of stabilizing agents and other chemicals. The reduced leachability is accomplished by the formation of a lattice structure and/or chemical bonds that bind the metals to the solid matrix and thereby limit the amount of metal constituents that can be leached when water or a mild acid solution comes into contact with the waste material.

The two principal stabilization processes used are cement-based and lime/pozzolan-based processes. A brief discussion of each is provided below. In both cement-based or lime/pozzolan-based techniques, the stabilizing process can be modified through the use of additives, such as silicates, that control curing rates, reduce permeability, and enhance the properties of the solid material.

(a) Portland cement-based process. Portland cement is a mixture of powdered oxides of calcium, silica, aluminum, and iron, produced by kiln burning of materials rich in calcium and silica at high temperatures (i.e., 1,400 to 1,500°C (2,552 to 2,732°F)). When the anhydrous cement powder is mixed with water, hydration occurs and the cement begins to set. The chemistry involved is complex because many different reactions occur, depending on the composition of the cement mixture.

As the cement begins to set, a colloidal gel of indefinite composition and structure is formed. Over time, the gel swells and forms a matrix composed of interlacing, thin, densely packed silicate fibrils. Constituents present in the waste slurry (e.g., hydroxides and carbonates of various metals) are incorporated into the interstices of the cement matrix. The high pH of the cement mixture tends to keep metals in the form of insoluble hydroxide and carbonate salts. It has been hypothesized that metal ions may also be incorporated into the crystal structure of the cement matrix, but this hypothesis has not been verified.

(b) Lime/pozzolan-based process. Pozzolan, which contains finely divided, noncrystalline silica (e.g., fly ash or components of cement kiln dust), is a material that is not cementitious in itself, but becomes so upon the addition of lime. Metals in the waste are converted to insoluble silicates or hydroxides and are incorporated into the interstices of the binder matrix, thereby inhibiting leaching.

(3) Description of stabilization process. The stabilization process consists of a weighing device, a mixing unit, and a curing vessel or pad. Commercial concrete mixing and handling equipment is typically used in stabilization processes. Weighing conveyors, metering cement hoppers, and mixers similar to concrete batching plants have been adapted in some operations. When extremely dangerous materials are treated, remote-control and in-drum mixing equipment, such as that used with nuclear waste, is employed.

In most stabilization processes, the waste, stabilizing agent, and other additives, if used, are mixed in a mixing vessel and then transferred to a curing vessel or pad and allowed to cure. The actual operation (equipment requirements and process sequencing) depends on several factors, including the nature of the waste, the quantity of the waste, the location of the waste in relation to the disposal site, the particular stabilization formulation used, and the curing rate. Following curing, the stabilized solid formed is recovered from the processing equipment and disposed of.

(4) Waste characteristics affecting performance (WCAPs). In determining whether stabilization will achieve the same level of performance on an untested waste as on a previously tested waste and whether performance levels can be transferred, EPA examines the following waste characteristics: (a) the concentration of fine particulates, (b) the concentration of oil and grease, (c) the concentration of organic compounds, and (d) the concentration of sulfate and chloride compounds.

(a) Concentration of fine particulates. For both cement-based and lime/pozzolan-based processes, very fine solid materials (i.e., those that pass through a No. 200 mesh sieve (less than 74-um particle size)) weaken the bonding between waste particles and the cement or lime/pozzolan binder by coating the particles. This coating inhibits chemical bond formation, thereby decreasing the resistance of the material to leaching. If the concentration of fine particulates in an untested waste is significantly higher than that in the tested waste, the system may not achieve the same performance. Pretreatment of the waste may be required to reduce the fine particulate concentration and achieve the same treatment performance, or other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(b) Concentration of oil and grease. Oil and grease in both cement-based and lime/pozzolan-based systems results in the coating of waste particles and the weakening of the bonding between the particle and the stabilizing agent, thereby decreasing the resistance of the material to leaching. If the concentration of oil and grease in the untested waste is significantly higher than that in the tested waste, the system may not achieve the same performance. Pretreatment may be required to reduce the oil and grease concentration and achieve the same treatment performance, or other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(c) Concentration of organic compounds. Organic compounds in the waste interfere with the stabilization chemical reactions and bond formation, thus inhibiting curing of the stabilized material. This results in a stabilized waste having decreased resistance to leaching. If the total organic carbon (TOC) content of the untested waste is significantly higher than that of the tested waste, the system may not achieve the same performance. Pretreatment may be required to reduce the TOC and achieve the same treatment performance, or other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(d) Concentration of sulfate and chloride compounds. Sulfate and chloride compounds interfere with the stabilization chemical reactions, weakening bond strength and prolonging setting and curing time. Sulfate and chloride compounds may reduce the dimensional stability of the cured matrix, thereby increasing leachability potential. If the concentration of sulfate and chloride compounds in the untested waste is significantly higher than that in the tested waste, the system may not achieve the same performance. Pretreatment may be required to reduce the sulfate and chloride concentrations and achieve the same treatment performance, or other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(5) Design and operating parameters. In assessing the effectiveness of the design and operation of a stabilization system, EPA examines the following parameters: (a) the amount and type of stabilizing agent and additives, (b) the degree of mixing, (c) the residence time, and (d) the stabilization temperature and humidity.

(a) Amount and type of stabilizing agent and additives. The stabilizing agent and additives used will determine the chemistry and structure of the stabilized material and therefore its leachability. Stabilizing agents and additives must be carefully selected based on the chemical and physical characteristics of the waste to be stabilized. To select the most effective type of stabilizing agent and additives, the waste should be tested in the laboratory with a variety of these materials to determine the best combination.

The amount of stabilizing agent and additives is a critical parameter in that sufficient stabilizing materials are necessary to properly bind the waste constituents of concern, making them less susceptible to leaching. The appropriate weight ratios of stabilizing agent and additives to waste are established empirically by setting up a series of laboratory tests that allow separate leachate testing of different mix ratios. The ratio of water to stabilizing agent (including water in waste) will also impact the strength and leaching characteristics of the stabilized material. Too much water will cause low strength; too little will make mixing difficult and, more important, may not allow the chemical reactions that bind the hazardous constituents to be fully completed. EPA evaluates the amount of stabilizing agent, water, and other additives used in the stabilization process to ensure that sufficient stabilizing materials are added to the waste to effectively immobilize the waste constituents of concern.

(b) Degree of mixing. Mixing is necessary to ensure homogeneous distribution of the waste, stabilizing agent, and additives. Both undermixing and overmixing are undesirable. The first condition results in a nonhomogeneous mixture; therefore, areas will exist within the waste where waste particles are neither chemically bonded to the stabilizing agent nor physically held within the lattice structure. Overmixing, on the other hand, may inhibit gel formation and ion adsorption in some stabilization systems. Optimal mixing conditions generally are determined through laboratory tests. The quantifiable degree of mixing is a complex assessment that includes, among other factors, the amount of energy supplied, the length of time the material is mixed, and the related turbulence effects of the specific size and shape of the mix tank or vessel. This is beyond the scope of simple measurement. EPA, however, evaluates the degree of mixing qualitatively by considering whether mixing is provided and whether the type of mixing device is one that could be expected to achieve homogeneous distribution of the waste, stabilizing agent, and additives.

(c) Residence time. The residence time or duration of curing ensures that the waste particles have had sufficient time in which to incorporate into lattice structures and/or form stable chemical bonds.

The time necessary for complete stabilization depends upon the waste and the stabilization process used. The performance of the stabilized waste (i.e., the levels of waste constituents in the leachate) will be highly dependent upon whether complete stabilization has occurred. Typical residence times range from 7 to 28 days. EPA monitors the residence time to ensure that sufficient time is provided to effectively stabilize the waste.

(d) Stabilization temperature and humidity. Higher temperatures and lower humidity increase the rate of curing by increasing the rate of evaporation of water from the stabilization mixtures. If temperatures are too high, however, the evaporation rate can be excessive, resulting in too little water being available for completion of the stabilization reaction. EPA monitors the stabilization temperature and humidity continuously, if possible, to ensure that the system is operating at the appropriate design conditions and to diagnose operational problems.

3.4.6 High Temperature Metals Recovery

(1) Applicability. High temperature metals recovery (HTMR) is a technology applicable to wastes containing metal oxides and metal salts (including cadmium, chromium, lead, nickel, and zinc compounds) at concentrations ranging from 10 percent to over 70 percent with low levels (i.e., below 5 percent) of organics and water in the wastes. There are a number of different types of high temperature metals recovery systems, which generally differ from one another in the source of energy used and

the method of recovery. These HTMR systems include the rotary kiln process, the plasma arc reactor, the rotary hearth electric furnace system, the molten slag reactor, and the flame reactor.

HTMR is generally not used for mercury-containing wastes even though mercury will volatilize readily at the process temperatures present in the high temperature units. The retorting process is normally used for mercury recovery because mercury is very volatile and lower operating temperatures can be used. Thus, the retorting process is more economical than HTMR for mercury-bearing wastes.

The HTMR process has been demonstrated on wastes such as baghouse dusts and dewatered scrubber sludge from the production of steels and ferroalloys. Zinc, cadmium, and lead are the metals most frequently recovered. The process has not been extensively evaluated for use with metal sulfides. The sulfides are chemically identical to natural minerals ordinarily present in ores used as feedstocks by primary smelters. Some sulfide-bearing wastes from the chrome pigments industry have been sent to such primary smelters. However, with sulfides, a possibility exists for formation of either carbon disulfide from reaction with carbon or sulfur dioxide from reaction with oxygen in the HTMR processes.

Metal halide salts are also not directly used in HTMR processes. They, however, may be converted to oxides or hydroxides, which are acceptable feedstocks for HTMR processes.

(2) Underlying principles of operation. The basic principle of operation for this technology is that metal oxides and salts are separated from a waste through a high temperature thermal reduction process that uses carbon, limestone, and silica (sand) as raw materials. The carbon acts as a reducing agent and reacts with metal oxides to generate carbon dioxide and free metal. The silica and limestone serve as fluxing agents. This process yields a metal product for reuse and reduces the concentration of metals in the residuals and, hence, the amount of waste that needs to be land disposed. An example HTMR reaction is the recovery of zinc, which proceeds as follows:

$$2\ ZnO + C \rightarrow 2\ Zn + CO_2$$

(3) Description of high temperature metals recovery process. The HTMR process consists of a mixing unit, a high temperature processing unit (kiln, furnace, etc.), a product collection system, and a residual treatment system. A schematic diagram for a high temperature metals recovery system is shown in Figure 3-10.

The mixing unit homogenizes metal-bearing wastes, thus minimizing feed variations to the high temperature processing unit. Before the wastes are fed into the high temperature processing unit, fluxing agents and carbon can be added to the mixing unit and mixed with the wastes. The fluxes used (sand and limestone) are often added to react with certain metal components, preventing their volatilization and resulting in an enhanced purity of the desired volatile metals removed.

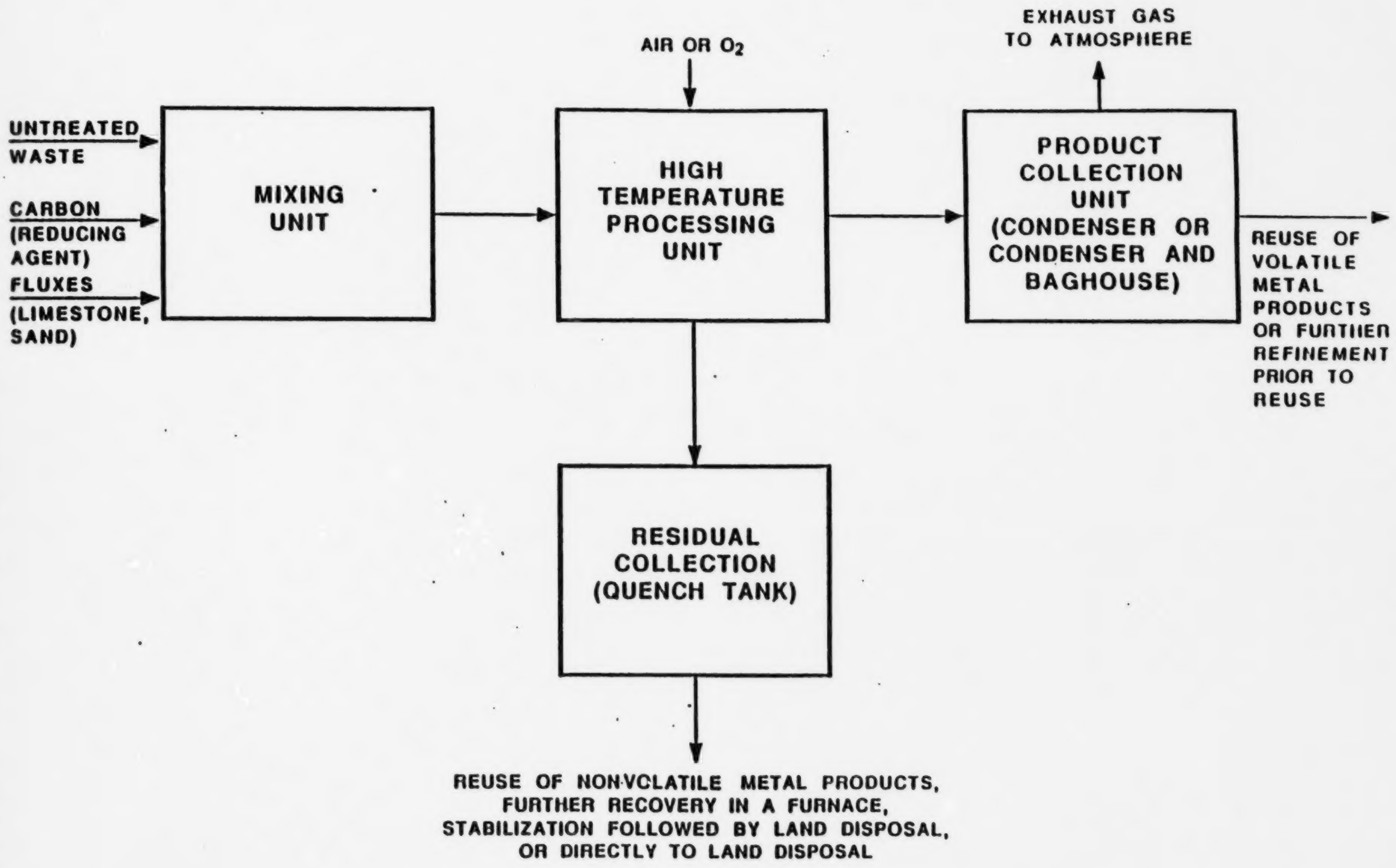

UNTREATED WASTE
CARBON (REDUCING AGENT)
FLUXES (LIMESTONE, SAND)
MIXING UNIT
AIR OR O_2
HIGH TEMPERATURE PROCESSING UNIT
EXHAUST GAS TO ATMOSPHERE
PRODUCT COLLECTION UNIT (CONDENSER OR CONDENSER AND BAGHOUSE)
REUSE OF VOLATILE METAL PRODUCTS OR FURTHER REFINEMENT PRIOR TO REUSE
RESIDUAL COLLECTION (QUENCH TANK)
REUSE OF NON-VOLATILE METAL PRODUCTS, FURTHER RECOVERY IN A FURNACE, STABILIZATION FOLLOWED BY LAND DISPOSAL, OR DIRECTLY TO LAND DISPOSAL

FIGURE 3-10 HIGH TEMPERATURE METALS RECOVERY SYSTEM

The blended waste materials are fed to a furnace, where they are heated to temperatures ranging from 1100 to 1400°C (2012 to 2552°F), resulting in the reduction and volatilization of the desired metals. The combination of temperature, residence time, and turbulence provided by rotation of the unit or addition of an air or oxygen stream helps ensure the maximum reduction and volatilization of metal constituents.

The product collection system can consist of either a condenser or a combination condenser and baghouse. The choice of a particular system depends on whether the metal is to be collected in the metallic form or as an oxide. Recovery and collection are accomplished for the metallic form by condensation alone, and for the oxide by reoxidation, condensation, and subsequent collection of the metal oxide particulates in a baghouse. There is no difference in these two types of metal recovery and collection systems relative to the kinds of waste that can be treated; the use of one system or the other simply reflects the facility's preference relative to product purity. In the former case, the direct condensation of metals allows for the separation and collection of individual metals in a relatively uncontaminated form; in the latter case, the metals are collected as a combination of several metal oxides.

The treated waste residual slag, containing higher concentrations of the less-volatile metals than the untreated waste, is sometimes cooled in a quench tank and (a) reused directly as a product (e.g., a waste residual containing mostly iron can be reused in steelmaking); (b) reused after further processing (e.g., a waste residual containing oxides of iron, chromium, and nickel can be reduced to metallic form and then recovered for use in the manufacture of stainless steel); or, if the material has no recoverable value, (c) stabilized, to immobilize any remaining metal constituents, and land disposed; or (d) directly land disposed as a slag.

(4) Waste characteristics affecting performance (WCAPs). In determining whether high temperature metals recovery will achieve the same level of performance on an untested waste as on a previously tested waste and whether performance levels can be transferred, EPA examines the following waste characteristics: (a) the concentrations of undesirable volatile metals, (b) the metal constituent boiling points, and (c) the thermal conductivity of the waste.

(a) Concentration of undesirable volatile metals. Because HTMR is a recovery process, the product must meet certain purity requirements prior to reuse. If the waste contains other volatile metals, such as arsenic or antimony, which are difficult to separate from the desired metal products and whose presence may affect the ability to reuse the product or refine it for subsequent reuse, HTMR may not be an appropriate technology. If the concentration of undesirable volatile metals in the untested waste is significantly higher than that in the tested waste, the system may not achieve the same performance and other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(b) Metal constituent boiling points. The greater the ratio of volatility of the waste constituents, the more easily the separation of these constituents can proceed. This ratio is called relative volatility. EPA recognizes, however, that the relative volatilities cannot be measured or calculated directly for the types of wastes generally treated by high temperature metals recovery, because the wastes usually consist of a myriad of components, all with different vapor pressure-versus-temperature relationships. However, because the volatility of components is usually inversely proportional to their boiling points (i.e., the higher the boiling point, the lower the volatility), EPA uses the boiling point of waste components as a surrogate waste characteristic for relative volatility. If the differences in boiling points between the more volatile and less volatile constituents are significantly lower in the untested waste than in the tested waste, the system may not achieve the same performance and other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(c) Thermal conductivity of the waste. The ability to heat constituents within an HTMR process feed matrix is a function of the heat transfer characteristics of the individual feed components (coke, limestone, untreated waste, etc.). The constituents being recovered from the waste must be heated to near or above their boiling points in order for them to be volatilized and recovered. The rate at which heat will be transferred to the feed mixture is dependent on the mixture's thermal conductivity, which is the ratio of the conductive heat flow to the temperature gradient across the material. Thermal conductivity measurements, as part of a treatability comparison of two different wastes to be treated by a single HTMR system, are most meaningful when applied to wastes that are homogeneous (i.e., uniform throughout). As wastes exhibit greater degrees of nonhomogeneity, thermal conductivity becomes less accurate in predicting treatability because the measurement reflects heat flow through regions having the greatest conductivity (i.e., the path of least resistance) and not heat flow through all parts of the waste. Nevertheless, EPA believes that thermal conductivity may provide the best measure of performance of heat transfer. If the thermal conductivity of the untested waste is significantly lower than that of the tested waste, the system may not achieve the same performance and other, more applicable treatment technologies may need to be considered for treatment of the untested waste.

(5) Design and operating parameters. In assessing the effectiveness of the design and operation of an HTMR system, EPA examines the following parameters: (a) the HTMR temperature, (b) the residence time, (c) the degree of mixing, (d) the carbon content of the feed, and (e) the calcium-to-silica ratio of the feed.

(a) HTMR temperature. Temperature provides an indirect measure of the energy available (i.e., Btu/hr) to volatilize the metal waste constituents. The higher the temperature in the high temperature processor, the more likely it is that the constituents will react with carbon to form free metals and volatilize. The temperature must be at least equal to or greater than the boiling point of the metals being volatilized for recovery. However, excessive temperatures could volatilize less-volatile, undesirable metals into the product, possibly inhibiting the potential for reuse of the product. EPA monitors the HTMR processor temperature continuously, if possible, to ensure that the system is operating at the appropriate design condition (at or above the boiling point(s) of the metal or metals being recovered, but not excessively high so as to volatilize other unwanted constituents) and to diagnose operational problems.

(b) Residence time. The residence time impacts the amount of volatile metals volatilized and recovered. It is dependent on the HTMR processor temperature and the thermal conductivity of the feed blend. EPA monitors the residence time to ensure that sufficient time is provided to effectively volatilize the volatile constituents for recovery.

(c) Degree of mixing. Effective mixing of the waste with coke, silica, and limestone is necessary to produce a uniform feed blend to the system. The quantifiable degree of mixing is a complex assessment that includes, among other things, the amount of energy supplied, the length of time the material is mixed, and the related turbulence effects of the specific size and shape of the tank or vessel. This is beyond the scope of simple measurement.

EPA, however, evaluates the degree of mixing qualitatively by considering whether mixing is provided and whether the type of mixing device is one that could be expected to achieve uniform mixing of the waste.

(d) Carbon content of the feed. The amount of carbon added to the waste must be sufficient to ensure complete reduction of the volatile metals being recovered. EPA examines the basis for calculation of the amount of carbon added to the waste to ensure that sufficient carbon is being used in the feed blend to effectively reduce metal compounds.

(e) Calcium-to-silica ratio of the feed. The calcium-to-silica ratio in the feed blend must be controlled to limit precipitation of metallic iron in the high temperature processor. The iron forms as solid calcium iron silicate, which is very difficult to subsequently process into any useful material. Aluminum oxide will also undergo reactions with lime and silica to form calcium aluminosilicates, which will lower the density and increase the volume of slag generated.

Precipitates and modified slags affect the reduction, volatilization, and recovery of volatile metals by changing heat flow characteristics in the system and by undergoing secondary, high temperature chemical reactions with metal oxides in the feed, converting them to the previously noted inert metal silicates or silicoaluminates. The ratio of calcium to silica to be used is dependent on the waste composition. Generally, a one-to-one silica-to-calcium oxide ratio is highly desired, so amounts of limestone and sand need to be adjusted based on the calcium and silica content of the waste to achieve this ratio.

Excess lime may also be added to fix sulfur in the feed as calcium sulfate. This will prevent the volatile metals from reacting with sulfur to form metal sulfides, thereby lowering the recovery of metals or oxides. EPA monitors the amounts of limestone and sand added to the waste to ensure that the calcium-to-silica ratio selected to maximize metal or oxide recovery is maintained during treatment.

4. TREATMENT PERFORMANCE DATA BASE

This section presents all data available to EPA on the performance of the demonstrated technologies discussed in Section 3 for treating F006 through F012 wastes. These data are used elsewhere in this document for determining which technologies represent BDAT (Section 5), for selecting constituents to be regulated (Section 6), and for developing the proposed treatment standards (Section 7). In addition to full-scale demonstration data, available data may include data developed at research facilities, or through other applications at less than full-scale operation, as long as the technology is demonstrated in full-scale operation for a similar waste or wastes as defined in Section 3.

Performance data include the untreated and treated waste concentrations for a given constituent, the values of operating parameters that were measured at the time the waste was being treated, the values of relevant design parameters for the treatment technology, and data on waste characteristics that affect performance of the treatment technology. EPA has provided all such data, to the extent that they are available, in Tables 4-1 through 4-14 found at the end of this section.

Where data are not available on the treatment of the specific wastes of concern, the Agency may elect to transfer data on the treatment of a similar waste or wastes using a demonstrated technology. To transfer data from another waste category, EPA must find that the wastes covered by this background document are no more difficult to treat (based on the waste characteristics that affect performance of the demonstrated treatment technology) than the treated wastes from which performance data are being transferred.

4.1 Electrolytic Oxidation/Alkaline Chlorination Data

At Plant A, the Agency collected one set of untreated and treated F011 waste samples from a batch treatment system that consisted of electrolytic oxidation, alkaline chlorination, chemical precipitation, filtration, and sludge dewatering (shown as Sample Set No. 1 in Table 4-1). The Agency also collected one set of samples from treatment of heat treating quenching wastewaters by the same treatment system as above except for the electrolytic oxidation step (shown as Sample Set No. 2 in Table 4-1). These data show, along with design and operating information, the total concentrations of metals and cyanide in the untreated waste, the treated wastewater (after precipitation of metals and filtration for removal of suspended solids), the treated nonwastewater (the precipitated solids from chemical precipitation, treated further by sludge dewatering), and concentrations of metals in the treated nonwastewater.

4.2 Wet Air Oxidation Data

In an EPA test at Plant B, the Agency collected six sets of data for untreated and treated F007 waste using a pilot-scale wet air oxidation treatment system. These data, presented in Table 4-2, show, along with design and operating information, the total concentration of metals and cyanide in the untreated waste, the treated wastewater, and the treated nonwastewater, as well as the TCLP leachate concentrations of metals in the nonwastewater treatment residual (reactor wall scale and reactor bottom solids). Concentration ranges are presented for the untreated waste composition data. For exact concentrations, refer to the CBI docket for Second Third land disposal restrictions, which is available through the OSW Document Control Officer.

4.3 Alkaline Chlorination Data

The Agency reviewed data submitted by Plant C on treatment of a variety of cyanide wastes by batch alkaline chlorination (CyanoKEM 1989). The data show concentration of total cyanide and metals in the untreated waste and concentration of total cyanide in both the treated wastewaters and the treated nonwastewaters. These data, for 14 sample sets, are presented in Table 4-3. (Treatment data for mixed cyanide wastes were also submitted by Plant C prior to calculation of the proposed treatment standards for these wastes (CyanoKEM 1987). These data are presented in Table 4-7. The data show concentrations of total cyanide and metals in the untreated waste and amenable cyanide in the treated wastewater, as well as design and operating information for each test.)

The treatment process used at Plant C is a several step batch alkaline chlorination process. The cyanide wastes that are received by the plant are first separated into bulk simple cyanides and bulk complex cyanides. The bulk simple cyanides are treated by alkaline chlorination followed by chemical precipitation and decantation. This liquid phase is tested for total cyanide concentration. If the total cyanide concentration is less than 1.9 ppm, the liquid is sent to secondary treatment. The secondary treatment consists of equalization and clarification. The solids are held in a holding tank.

The bulk complex cyanides are treated in several steps. The first step is to destroy the simple cyanides by alkaline chlorination. The effluent from the alkaline chlorination process is sent through precipitation and decantation. The liquid phase will contain most of the simple cyanides. These simple cyanides are then treated in a manner similar to the bulk simple cyanides. The total cyanide concentration of the solids is tested and if the concentration of total cyanide is greater than 1,000 ppm, the solids are resolubilized and treated by alkaline chlorination followed by chemical precipitation and decantation. The liquid phase is treated by bulk simple cyanide process and the solids are further tested for total cyanide concentration. This repetitive treatment process continues until the solids concentration is less than 1,000 ppm.

The Agency believes that this process incorporates repetitive treatment for the concentrated cyanide wastes, i.e., greater than 30,000 ppm of total cyanides. The fact that repetitive treatment occurs does not call into question the achievability of the cyanide standard by one-step alkaline chlorination processes. In the first place, the wastes at Plant C require multistage treatment (in some cases) because they are heavily concentrated with cyanide and complexing metals. Normal electroplating wastes contain much lower concentrations of these key parameters. Thus, based on characterization data for electroplating wastes provided in Table 2-3 and the F006 waste composition data submitted in the Generator Survey (see Table B-12), the wastes treated at Plant C are much more concentrated than wastes from the electroplating process that are treated for cyanide destruction. Also, the Agency notes that if F006 wastewater treatment sludges at electroplating facilities do not meet the cyanide treatment standards, these wastes can be held in a holding tank and resolubilized and treated again by the plant's alkaline chlorination system. Most important, all existing data (public comments to this rulemaking and the Agency's review of the Generator Survey data, which corroborates the information in the public comments) show that the final cyanide treatment standard is being achieved by over 90 percent of the industry by performance of existing treatment systems.

Facility C supplied data to EPA on the proportion of cyanide and noncyanide wastes fed to the clarifier during treatment tests. The treated waste concentrations reported in Table 4-3 were adjusted to take into account these dilution factors. The clarification step is followed by chemical precipitation, polishing filtration, and sludge dewatering for metals removal. The clarification tank holds a large volume of wastes (approximately 4 days' residence time), thus also serving as an equalization tank between batches. Precipitation and filtration treatments are performed on the equalized waste, so that each treated waste sample corresponds to the treatment of four days' waste, rather than a specific treatment batch. The retention step in CyanoKEM's chemical precipitation of the metals process is not even related to cyanide treatment. (Cyanide destruction by alkaline chlorination actually occurs in 2 to 3 hours in the CyanoKEM batch process and occurs even more quickly in continuous alkaline chlorination processes.) This type of retention is not needed for successful treatment at a normal electroplating operation using alkaline chlorination. CyanoKEM treats much larger volumes of waste than the usual electroplater, and requires the extra retention to equalize the large volumes of waste before chemical precipitation.

The Agency also collected two sets of treatment data at Plant E, presented in Table 4-8. These data show total cyanide concentrations for both the influent and the effluent from alkaline chlorination treatment (USEPA 1985).

4.4 Electrolytic Oxidation Data

Table 4-4 presents 11 data sets obtained from the literature on the performance of electrolytic oxidation treatment of cyanide wastes (Easton 1967). The data show cyanide concentrations in the untreated and treated wastewater, as well as design and operating information obtained during the tests.

4.5 High-Temperature Cyanide Hydrolysis Data

Table 4-5 presents six data sets obtained from the literature from full-scale testing of high-temperature cyanide hydrolysis (Robey 1983). Wastes tested were actual F007-F009 electroplating wastes, in the form of both bulk liquids (wastewaters) and drummed solids (nonwastewaters).

4.6 SO_2/Air Oxidation Data

Table 4-9 presents seven sets of data on SO_2/air oxidation treatment of electroplating wastewaters, from various literature sources, submitted during the public comment period (Inco 1989). These data present total cyanide, BDAT list metals, and iron concentrations in both the untreated waste and the treated wastewater, as well as the available operating data for each test.

4.7 UV/Ozonolysis Data

Plant C also submitted two sets of data on ultraviolet light-enhanced ozonolysis treatment of a synthetic waste with a high iron cyanide content. The waste was prepared as a mixture of high-iron content wastes and then treated by bench-scale alkaline chlorination prior to "untreated waste" analysis. These data, presented in Table 4-10, include analysis of total cyanide, BDAT list metals, and iron in the untreated waste and total cyanide in the treated waste, as well as operating parameters for each test.

4.8 Chemical Precipitation Data

The data for BDAT metals from Plant A, shown in Table 4-1, show treatment of metals in wastewater by chemical precipitation followed by filtration and sludge dewatering. Additionally, the Agency has data for chromium reduction followed by chemical precipitation, filtration, and sludge dewatering for treatment of K062 and other wastes. (See EPA's BDAT Background Document for K062 (USEPA 1988b).)

4.9 Stabilization Data

The Agency has data on treatment of BDAT list metals in F006 waste by stabilization. (See EPA's BDAT Background Document for F006 (USEPA 1988a).) EPA has not identified any metals treatment data for F012 or similar wastes other than the data considered in developing treatment standards for F006, for which stabilization was determined to be BDAT.

Table 4-11 presents data on stabilization of an aluminum coil plating sludge containing cyanide, collected by EPA (USEPA 1988g). These data show total composition data for BDAT list metals and cyanide for the untreated waste and TCLP data for the same parameters for the treated waste. The table also presents data on other parameters affecting stabilization treatment.

4.10 Incineration Data

Plant D submitted two data sets on treatment of F010 waste and a similar waste by incineration, presented in Table 4-6 (CyanoKEM 1988). These data show total cyanide concentration in both the untreated waste and the treated solid residual (ash). No data were presented for the scrubber water.

4.11 Other Agency Data on Cyanide Treatment

The Agency has examined the data used for development of the effluent limitations guidelines (ELG) for the metal finishing point source category. Most of the treatment data used to develop the ELG standards consisted of treated waste data from monitoring of plant effluent streams and did not present associated untreated waste data. Tables 4-12 and 4-13 present those data that were presented as paired influent-effluent data (USEPA 1983). These data are for chemical precipitation and ozonation treatment, respectively. The data presented in these tables show untreated waste cyanide concentrations much lower than for the treatment data that are presented in Tables 4-1 through 4-11. Table 4-14 summarizes the data used to develop the effluent guidelines limitations and standards for the metal finishing point source category (effluent data only).

Table 4-1 Electrolytic Oxidation, Alkaline Chlorination, Chemical Precipitation, and Sludge Dewatering Data Collected by EPA at Plant A for Treatment of F011 and Heat Treating Quenching Wastewaters

Sample Set No. 1[a]

	Concentration			
	Untreated waste	Treated wastewater	Treated nonwastewater	
Constituent	Total (mg/l)	Total (mg/l)	Total (mg/kg)	TCLP (mg/l)
Antimony	0.029	<0.021	<2.1	<0.021
Barium	1.0	0.084	19	0.301
Cadmium	0.01	<0.004	1.4	0.016
Chromium (hexavalent)	<0.01	8.95	-	0.259
Chromium (total)	5.42	6.55	39	0.236
Copper	1.03	0.043	72	0.076
Iron	27.8	28.6	1,670	<0.04
Lead	1.1	<0.05	22	0.011
Mercury	<0.00025	0.00022	<0.10	<0.0002
Nickel	2.88	0.58	519	3.06
Silver	0.0072	0.012	<0.20	<0.002
Vanadium	0.156	0.032	7.0	0.014
Zinc	0.338	0.03	31	0.352
Cyanide (amenable)	I	3.0[b]	19.9	-
Cyanide (total)	5,350	117[b]	99.4	-
Oil and grease	11.0	-	220	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Electrolytic oxidation reactor temperature	170-180°F	175-180°F
Electrolytic oxidation reactor pH	>11.0	10.6-11.6
Alkaline chlorination reactor pH (2-step)	>11.0; 7.0-9.0	11.2; 8.0
Excess chlorine in alkaline chlorination reactor	NS	30 mg/l

I = Sample result is indeterminate because of analytical interference, but is less than 5,130 mg/l based on laboratory analysis of total and amenable cyanides for the partially treated waste.

- = Not analyzed.

NS = Not specified.

[a] Electrolytic oxidation was used only with Sample Set No. 1.

[b] Accuracy-adjusted concentration.

Reference: USEPA 1988e.

Table 4-1 (continued)

Alkaline Chlorination, Chemical Precipitation, and Sludge Dewatering
Data Collected by EPA at Plant A for Heat Treating Quenching Wastewaters

Sample Set No. 2

	Concentration			
	Untreated waste	Treated wastewater	Treated nonwastewater	
Constituent	Total (mg/l)	Total (mg/l)	Total (mg/kg)	TCLP (mg/l)
Antimony	<0.021	<0.021	<2.1	<0.021
Barium	0.158	0.102	98	0.312
Cadmium	0.057	0.0092	5.31	0.052
Chromium (hexavalent)	<0.01	0.625	-	0.436
Chromium (total)	0.175	1.63	11	0.31
Copper	1.08	0.035	307	0.354
Iron	11.14	2.96	2,880	0.029
Lead	0.063	<0.005	28	0.01
Mercury	<0.0002	0.00032	<0.1	<0.0002
Nickel	10.9	0.64	758	5.9
Silver	0.064	0.094	0.73	0.034
Vanadium	0.043	0.011	6.7	0.0061
Zinc	0.60	0.147	54	0.377
Cyanide (amenable)	29.2	<0.01	5.6	-
Cyanide (total)	62.6	<0.01	34.7	-
Oil and grease	2.3	-	432	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Alkaline chlorination reactor pH	>11.0; 7.0-9.0	11.6; 7.6
Excess chlorine in alkaline chlorination reactor	NS	120 mg/l

- = Not analyzed.
NS = Not specified.

Reference: USEPA 1988e.

Table 4-2 Wet Air Oxidation Data Collected by EPA at Plant B for F007 Waste

Sample Set No. 1

	Concentration					
			Treated nonwastewater			
	Untreated waste	Treated wastewater	Reactor solids A[a]		Reactor solids B[b]	
Constituent	Total (mg/l)	Total (mg/l)	Total (mg/kg)	TCLP (mg/l)	Total (mg/kg)	TCLP (mg/l)
BDAT Organics						
Methanol	CBI	266	<15	-	<15	-
BDAT Inorganics						
Antimony	CBI	<4.0	<350	-	<35	-
Arsenic	CBI	<0.05	<1.0	<0.01	<1.0	<0.01
Barium	CBI	0.047	1.25	0.20	6.4	0.17
Beryllium	CBI	<0.075	<0.15	-	<1.5	-
Cadmium	CBI	<0.06	<1.25	<0.10	<1.0	<0.10
Chromium (hexavalent)	CBI	I	I	I	I	I
Chromium (total)	CBI	0.628	2.55	<0.10	6.09	<0.10
Copper	CBI	759	151,000	-	44,400	-
Lead	CBI	<1.75	<35	<2.0	<35	<2.0
Mercury	CBI	<0.015	<1.0	<0.05	<1.0	<0.05
Nickel	CBI	<0.25	33.7	-	26.5	-
Selenium	CBI	<0.045	<1.0	<0.01	<1.0	<0.01
Silver	CBI	<0.55	<10	<1.0	<8.0	<1.0
Thallium	CBI	<2.0	<40	-	<40	-
Vanadium	CBI	<0.125	<2.5	-	5.3	-
Zinc	CBI	7.91	29,600	-	139,000	-
Cyanide (amenable)	CBI	0.3	<25	-	<25	-
Cyanide (total)	CBI	11.9	<25	-	<25	-
Fluoride	CBI	4.20	-	-	-	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Reactor temperature	440-480°F	449-487°F
Residence time	55-66 min (5.0-6.0 gal/hr)	57.1 min
Oxygen concentration (off-gas)	16-20%	17.8%
Reactor pressure	1700 psig	1690-1707 psig

I = Matrix interference.

- = Not analyzed.

[a] Reactor wall scale; one sample collected for all six sample sets.

[b] Reactor bottom solids; one sample collected for all six sample sets.

Reference: USEPA 1988f.

Table 4-2 (continued)

Sample Set No. 2

	Concentration					
			Treated nonwastewater			
	Untreated waste	Treated wastewater	Reactor solids A[a]		Reactor solids B[b]	
Constituent	Total (mg/l)	Total (mg/l)	Total (mg/kg)	TCLP (mg/l)	Total (mg/kg)	TCLP (mg/l)
BDAT Organics						
Methanol	CBI	<150	<15	-	<15	-
BDAT Inorganics						
Antimony	CBI	<4.0	<350	-	<35	-
Arsenic	CBI	<0.05	<1.0	<0.01	<1.0	<0.01
Barium	CBI	<0.03	1.25	0.20	6.4	0.17
Beryllium	CBI	<0.075	<0.15	-	<1.5	-
Cadmium	CBI	0.17	<1.25	<0.10	<1.0	<0.10
Chromium (hexavalent)	CBI	I	I	I	I	I
Chromium (total)	CBI	0.478	2.55	<0.10	6.09	<0.10
Copper	CBI	568	151,000	-	44,400	-
Lead	CBI	<1.75	<35	<2.0	<35	<2.0
Mercury	CBI	<0.015	<1.0	<0.05	<1.0	<0.05
Nickel	CBI	<0.25	33.7	-	26.5	-
Selenium	CBI	<0.045	<1.0	<0.01	<1.0	<0.01
Silver	CBI	<0.55	<10	<1.0	<8.0	<1.0
Thallium	CBI	<2.0	<40	-	<40	-
Vanadium	CBI	<0.125	<2.5	-	5.3	-
Zinc	CBI	7.48	29,600	-	139,000	-
Cyanide (amenable)	CBI	<0.25	<25	-	<25	-
Cyanide (total)	CBI	<0.25	<25	-	<25	-
Fluoride	CBI	4.02	-	-	-	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Reactor temperature	440-480°F	440-489°F
Residence time	55-66 min (5.0-6.0 gal/hr)	60.5 min
Oxygen concentration (off-gas)	16-20%	17.0%
Reactor pressure	1700 psig	1709-1725 psig

I = Matrix interference.

- = Not analyzed.

[a] Reactor wall scale; one sample collected for all six sample sets.

[b] Reactor bottom solids; one sample collected for all six sample sets.

Reference: USEPA 1988f.

Table 4-2 (continued)

Sample Set No. 3

	Concentration					
			Treated nonwastewater			
	Untreated waste	Treated wastewater	Reactor solids A[a]		Reactor solids B[b]	
Constituent	Total (mg/l)	Total (mg/l)	Total (mg/kg)	TCLP (mg/l)	Total (mg/kg)	TCLP (mg/l)
BDAT Organics						
Methanol	CBI	110	<15	-	<15	-
BDAT Inorganics						
Antimony	CBI	<4.0	<350	-	<35	-
Arsenic	CBI	<0.05	<1.0	<0.01	<1.0	<0.01
Barium	CBI	0.038	1.25	0.20	6.4	0.17
Beryllium	CBI	<0.075	<0.15	-	<1.5	-
Cadmium	CBI	0.48	<1.25	<0.10	<1.0	<0.10
Chromium (hexavalent)	CBI	I	I	I	I	I
Chromium (total)	CBI	0.568	2.55	<0.10	6.09	<0.10
Copper	CBI	834	151,000	-	44,400	-
Lead	CBI	<1.75	<35	<2.0	<35	<2.0
Mercury	CBI	<0.015	<1.0	<0.05	<1.0	<0.05
Nickel	CBI	<0.25	33.7	-	26.5	-
Selenium	CBI	<0.045	<1.0	<0.01	<1.0	<0.01
Silver	CBI	<0.55	<10	<1.0	<8.0	<1.0
Thallium	CBI	<2.0	<40	-	<40	-
Vanadium	CBI	<0.125	<2.5	-	5.3	-
Zinc	CBI	4.63	29,600	-	139,000	-
Cyanide (amenable)	CBI	<0.25	<25	-	<25	-
Cyanide (total)	CBI	3.22	<25	-	<25	-
Fluoride	CBI	4.02	-	-	-	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Reactor temperature	440-480°F	431-488°F
Residence time	55-66 min (5.0-6.0 gal/hr)	59.2 min
Oxygen concentration (off-gas)	16-20%	17.5%
Reactor pressure	1700 psig	1701-1718 psig

I = Matrix interference.
- = Not analyzed.

[a] Reactor wall scale; one sample collected for all six sample sets.

[b] Reactor bottom solids; one sample collected for all six sample sets.

Reference: USEPA 1988f.

Table 4-2 (continued)

Sample Set No. 4

	Concentration					
			Treated nonwastewater			
	Untreated waste	Treated wastewater	Reactor solids A[a]		Reactor solids B[b]	
Constituent	Total (mg/l)	Total (mg/l)	Total (mg/kg)	TCLP (mg/l)	Total (mg/kg)	TCLP (mg/l)
BDAT Organics						
Methanol	CBI	64	<15	-	<15	-
BDAT Inorganics						
Antimony	CBI	<4.0	<350	-	<35	-
Arsenic	CBI	<0.05	<1.0	<0.01	<1.0	<0.01
Barium	CBI	<0.30	1.25	0.20	6.4	0.17
Beryllium	CBI	<0.75	<0.15	-	<1.5	-
Cadmium	CBI	<0.60	<1.25	<0.10	<1.0	<0.10
Chromium (hexavalent)	CBI	I	I	I	I	I
Chromium (total)	CBI	<0.90	2.55	<0.10	6.09	<0.10
Copper	CBI	766	151,000	-	44,400	-
Lead	CBI	<17.5	<35	<2.0	<35	<2.0
Mercury	CBI	<0.015	<1.0	<0.05	<1.0	<0.05
Nickel	CBI	<2.5	33.7	-	26.5	-
Selenium	CBI	<0.045	<1.0	<0.01	<1.0	<0.01
Silver	CBI	<5.5	<10	<1.0	<8.0	<1.0
Thallium	CBI	<20	<40	-	<40	-
Vanadium	CBI	<1.25	<2.5	-	5.3	-
Zinc	CBI	6.26	29,600	-	139,000	-
Cyanide (amenable)	CBI	<0.25	<25	-	<25	-
Cyanide (total)	CBI	<0.25	<25	-	<25	-
Fluoride	CBI	4.07	-	-	-	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Reactor temperature	440-480°F	424-493°F
Residence time	55-66 min (5.0-6.0 gal/hr)	53.3 min
Oxygen concentration (off-gas)	16-20%	16.5%
Reactor pressure	1700 psig	1675-1740 psig

I = Matrix interference.
- = Not analyzed.

[a] Reactor wall scale; one sample collected for all six sample sets.

[b] Reactor bottom solids; one sample collected for all six sample sets.

Reference: USEPA 1988f.

Table 4-2 (continued)

Sample Set No. 5

	Concentration					
			Treated nonwastewater			
	Untreated waste	Treated wastewater	Reactor solids A[a]		Reactor solids B[b]	
Constituent	Total (mg/l)	Total (mg/l)	Total (mg/kg)	TCLP (mg/l)	Total (mg/kg)	TCLP (mg/l)
BDAT Organics						
Methanol	CBI	50	<15	-	<15	-
BDAT Inorganics						
Antimony	CBI	<4.0	<350	-	<35	-
Arsenic	CBI	<0.05	<1.0	<0.01	<1.0	<0.01
Barium	CBI	<0.03	1.25	0.20	6.4	0.17
Beryllium	CBI	<0.075	<0.15	-	<1.5	-
Cadmium	CBI	<0.72	<1.25	<0.10	<1.0	<0.10
Chromium (hexavalent)	CBI	I	I	I	I	I
Chromium (total)	CBI	0.499	2.55	<0.10	6.09	<0.10
Copper	CBI	946	151,000	-	44,400	-
Lead	CBI	<1.75	<35	<2.0	<35	<2.0
Mercury	CBI	<0.015	<1.0	<0.05	<1.0	<0.05
Nickel	CBI	<0.25	33.7	-	26.5	-
Selenium	CBI	<0.045	<1.0	<0.01	<1.0	<0.01
Silver	CBI	<0.55	<10	<1.0	<8.0	<1.0
Thallium	CBI	<2.0	<40	-	<40	-
Vanadium	CBI	<0.125	<2.5	-	5.3	-
Zinc	CBI	4.07	29,600	-	139,000	-
Cyanide (amenable)	CBI	<0.25	<25	-	<25	-
Cyanide (total)	CBI	<0.25	<25	-	<25	-
Fluoride	CBI	4.06	-	-	-	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Reactor temperature	440-480°F	417-484°F
Residence time	55-66 min (5.0-6.0 gal/hr)	51.6 min
Oxygen concentration (off-gas)	16-20%	16.6%
Reactor pressure	1700 psig	1680-1694 psig

I = Matrix interference.
- = Not analyzed.

[a] Reactor wall scale; one sample collected for all six sample sets.
[b] Reactor bottom solids; one sample collected for all six sample sets.
Reference: USEPA 1988f.

Table 4-2 (continued)

Sample Set No. 6

	Concentration					
			Treated nonwastewater			
	Untreated waste	Treated wastewater	Reactor solids A[a]		Reactor solids B[b]	
Constituent	Total (mg/l)	Total (mg/l)	Total (mg/kg)	TCLP (mg/l)	Total (mg/kg)	TCLP (mg/l)
BDAT Organics						
Methanol	CBI	36	<15	-	<15	-
BDAT Inorganics						
Antimony	CBI	<4.0	<350	-	<35	-
Arsenic	CBI	<0.05	<1.0	<0.01	<1.0	<0.01
Barium	CBI	<0.6	1.25	0.20	6.4	0.17
Beryllium	CBI	<1.5	<0.15	-	<1.5	-
Cadmium	CBI	<1.2	<1.25	<0.10	<1.0	<0.10
Chromium (hexavalent)	CBI	I	I	I	I	I
Chromium (total)	CBI	<1.8	2.55	<0.10	6.09	<0.10
Copper	CBI	994	151,000	-	44,400	-
Lead	CBI	<35	<35	<2.0	<35	<2.0
Mercury	CBI	<0.015	<1.0	<0.05	<1.0	<0.05
Nickel	CBI	<5.0	33.7	-	26.5	-
Selenium	CBI	<0.045	<1.0	<0.01	<1.0	<0.01
Silver	CBI	<11	<10	<1.0	<8.0	<1.0
Thallium	CBI	<40	<40	-	<40	-
Vanadium	CBI	<2.5	<2.5	-	5.3	-
Zinc	CBI	8.46	29,600	-	139,000	-
Cyanide (amenable)	CBI	<0.25	<25	-	<25	-
Cyanide (total)	CBI	<0.25	<25	-	<25	-
Fluoride	CBI	3.95	-	-	-	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Reactor temperature	440-480°F	412-494°F
Residence time	55-66 min (5.0-6.0 gal/hr)	50.8 min
Oxygen concentration (off-gas)	16-20%	17.0%
Reactor pressure	1700 psig	1674-1690 psig

[a] Reactor wall scale; one sample collected for all six sample sets.

[b] Reactor bottom solids; one sample collected for all six sample sets.

I = Matrix interference.
- = Not analyzed.
Reference: USEPA 1988f.

Table 4-3 Alkaline Chlorination Data Submitted by Plant C During the Public Comment Period

Sample Set No 1[a] - for Treatment of F007, F008, D003, and P106

	Concentration		
Constituent/parameter	Untreated waste (mg/l)	Treated wastewater (mg/l)	Treated nonwastewater (mg/l)
BDAT Inorganics Other Than Metals			
Cyanide (total)	71,759	0.95	357
BDAT List Metals			
Copper	4,193	-	-
Nickel	136	-	-
Cadmium	2,995	-	-
Chromium	323	-	-
Lead	184	-	-
Zinc	2,319	-	-
Non-BDAT List Metals			
Iron	2,936	-	-
Other Parameters			
pH	11.2	-	-
TOC	<2%	-	-

- = Not analyzed.

[a] Batch consisted of a mixture of liquids and drummed solids including waste codes F007, F008, D003, and P106.

Reference: CyanoKEM 1989.

Table 4-3 (continued)

Sample Set No. 2[a] - for Treatment of F009, F012

	Concentration		
Constituent/parameter	Untreated waste (mg/l)	Treated wastewater (mg/l)	Treated nonwastewater (mg/l)
BDAT Inorganics Other Than Metals			
Cyanide (total)	12,000	0.95	153
BDAT List Metals			
Copper	1,339	-	-
Nickel	4,088	-	-
Cadmium	300	-	-
Chromium	592	-	-
Lead	327	-	-
Zinc	750	-	-
Non-BDAT List Metals			
Iron	6,200	-	-
Other Parameters			
pH	11.0	-	-
TOC	<2%	-	-

- = Not analyzed.

[a] Batch consisted of a mixture of liquids and drummed solids including waste codes F009 and F012.

Reference: CyanoKEM 1989.

Table 4-3 (continued)

Sample Set No. 3[a] - for Treatment of F009, D002, D003, and P030

	Concentration		
Constituent/parameter	Untreated waste (mg/l)	Treated wastewater (mg/l)	Treated nonwastewater (mg/l)
BDAT Inorganics Other Than Metals			
Cyanide (total)	17,206	<0.014	351
BDAT List Metals			
Copper	8,400	-	-
Nickel	1,290	-	-
Cadmium	7,610	-	-
Chromium	239	-	-
Lead	129	-	-
Zinc	5,150	-	-
Non-BDAT List Metals			
Iron	5,520	-	-
Other Parameters			
pH	11.2	-	-
TOC	<2%	-	-

- = Not analyzed.

[a] Batch consisted of a mixture of liquids and drummed solids including waste codes F009, D002, D003, and P030.

Reference: CyanoKEM 1989.

Table 4-3 (continued)

Sample Set No. 4[a] - for Treatment of F007, F009, and D002

	Concentration		
Constituent/parameter	Untreated waste (mg/l)	Treated wastewater (mg/l)	Treated nonwastewater (mg/l)
BDAT Inorganics Other Than Metals			
Cyanide (total)	25,936	<0.014	374
BDAT List Metals			
Copper	3,266	-	-
Nickel	7,172	-	-
Cadmium	1,482	-	-
Chromium	707	-	-
Lead	173	-	-
Zinc	2,389	-	-
Non-BDAT List Metals			
Iron	11,917	-	-
Other Parameters			
pH	11.5	-	-
TOC	<2%	-	-

- = Not analyzed

[a] Batch consisted of a mixture of liquids and drummed solids including waste codes F007, F009, and D002.

Reference: CyanoKEM 1989.

Table 4-3 (continued)

Sample Set No. 5[a] - for Treatment of F007, F008, D003, and P029

Constituent/parameter	Concentration Untreated waste (mg/l)	 Treated wastewater (mg/l)	 Treated nonwastewater (mg/l)
BDAT Inorganics Other Than Metals			
Cyanide (total)	16,914	<0.014	235
BDAT List Metals			
Copper	5,343	-	-
Nickel	151	-	-
Cadmium	3,412	-	-
Chromium	408	-	-
Lead	99	-	-
Zinc	3,483	-	-
Non-BDAT List Metals			
Iron	3,670	-	-
Other Parameters			
pH	11.0	-	-
TOC	<2%	-	-

- = Not analyzed.

[a] Batch consisted of a mixture of liquids and drummed solids including waste codes F007, F008, D003, and P029.

Reference: CyanoKEM 1989.

Table 4-3 (continued)

Sample Set No. 6[a] - for Treatment of F011, F012, D002, and P106

Constituent/parameter	Concentration Untreated waste (mg/l)	Treated wastewater (mg/l)	Treated nonwastewater (mg/l)
BDAT Inorganics Other Than Metals			
Cyanide (total)	59,421	0.028	245
BDAT List Metals			
Copper	922	-	-
Nickel	259	-	-
Cadmium	3,223	-	-
Chromium	180	-	-
Lead	142	-	-
Zinc	5,143	-	-
Non-BDAT List Metals			
Iron	3,810	-	-
Other Parameters			
pH	11.3	-	-
TOC	<2%	-	-

- = Not analyzed.

[a] Batch consisted of a mixture of liquids and drummed solids including waste codes F011, F012, D002, and P106.

Reference: CyanoKEM 1989.

Table 4-3 (continued)

Sample Set No. 6[a] - for Treatment of F011, F012, D002, and P106

Constituent/parameter	Concentration Untreated waste (mg/l)	Treated wastewater (mg/l)	Treated nonwastewater (mg/l)
BDAT Inorganics Other Than Metals			
Cyanide (total)	59,421	0.028	245
BDAT List Metals			
Copper	922	-	-
Nickel	259	-	-
Cadmium	3,223	-	-
Chromium	180	-	-
Lead	142	-	-
Zinc	5,143	-	-
Non-BDAT List Metals			
Iron	3,810	-	-
Other Parameters			
pH	11.3	-	-
TOC	<2%	-	-

- = Not analyzed.

[a] Batch consisted of a mixture of liquids and drummed solids including waste codes F011, F012, D002, and P106.

Reference: CyanoKEM 1989.

Table 4-3 (continued)

Sample Set No. 7[a] - for Treatment of F007 and F009

Constituent/parameter	Concentration Untreated waste (mg/l)	 Treated wastewater (mg/l)	 Treated nonwastewater (mg/l)
BDAT Inorganics Other Than Metals			
Cyanide (total)	31,994	0.028	169
BDAT List Metals			
Copper	15,739	-	-
Nickel	1,897	-	-
Cadmium	944	-	-
Chromium	100	-	-
Lead	124	-	-
Zinc	3,187	-	-
Non-BDAT List Metals			
Iron	403	-	-
Other Parameters			
pH	11.2	-	-
TOC	<2%	-	-

- = Not analyzed.

[a] Batch consisted of a mixture of liquids and drummed solids including waste codes F007 and F009.

Reference: CyanoKEM 1989.

Table 4-3 (continued)

Sample Set No. 8 - for Treatment of F007

	Concentration		
Constituent/parameter	Untreated waste (mg/l)	Treated wastewater (mg/l)	Treated nonwastewater (mg/l)
BDAT Inorganics Other Than Metals			
Cyanide (total)	41,900	<0.014	189
BDAT List Metals			
Copper	19,510	-	-
Nickel	2,683	-	-
Cadmium	1,350	-	-
Chromium	100	-	-
Lead	138	-	-
Zinc	4,708	-	-
Non-BDAT List Metals			
Iron	498	-	-
Other Parameters			
pH	11.5	-	-
TOC	<2%	-	-

- = Not analyzed.

Reference: CyanoKEM 1989.

Table 4-3 (continued)

Sample Set No. 9[a] - for Treatment of F006, F009, F011, D002, and D003

Constituent/parameter	Concentration Untreated waste (mg/l)	Treated wastewater (mg/l)	Treated nonwastewater (mg/l)
BDAT Inorganics Other Than Metals			
Cyanide (total)	18,882	<0.014	106.3
BDAT List Metals			
Copper	11,654	-	-
Nickel	1,925	-	-
Cadmium	792	-	-
Chromium	3,658	-	-
Lead	289	-	-
Zinc	5,357	-	-
Non-BDAT List Metals			
Iron	6,713	-	-
Other Parameters			
pH	10.3	-	-
TOC	<2%	-	-

- = Not analyzed.

[a] Batch consisted of a mixture of liquids and drummed solids including waste codes F006, F009, F011, D002, and D003.

Reference: CyanoKEM 1989.

Table 4-3 (continued)

Sample Set No. 10[a] - for Treatment of F006 and F012

	Concentration		
Constituent/parameter	Untreated waste (mg/l)	Treated wastewater (mg/l)	Treated nonwastewater (mg/l)
BDAT Inorganics Other Than Metals			
Cyanide (total)	1,270	0.17	143
BDAT List Metals			
Copper	2,319	-	-
Nickel	6,739	-	-
Cadmium	1,903	-	-
Chromium	14,079	-	-
Lead	662	-	-
Zinc	19,163	-	-
Non-BDAT List Metals			
Iron	7,786	-	-
Other Parameters			
pH	10.0	-	-
TOC	<2%	-	-

- = Not analyzed.

[a] Batch consisted of a mixture of liquids and drummed solids including waste codes F006 and F012.

Reference: CyanoKEM 1989.

Table 4-3 (continued)

Sample Set No. 11[a] - for Treatment of F007, F009, D002, P029, and P030

	Concentration		
Constituent/parameter	Untreated waste (mg/l)	Treated wastewater (mg/l)	Treated nonwastewater (mg/l)
BDAT Inorganics Other Than Metals			
Cyanide (total)	22,820	1.16	114.1
BDAT List Metals			
Copper	7,910	-	-
Nickel	450	-	-
Cadmium	3,109	-	-
Chromium	<100	-	-
Lead	124	-	-
Zinc	4,695	-	-
Non-BDAT List Metals			
Iron	832	-	-
Other Parameters			
pH	11.2	-	-
TOC	<2%	-	-

- = Not analyzed.

[a] Batch consisted of a mixture of liquids and drummed solids including waste codes F007, F009, D002, P029, and P030.

Reference: CyanoKEM 1989.

Table 4-3 (continued)

Sample Set No. 12[a] - for Treatment of F007, F009, F012, and D003

Constituent/parameter	Concentration Untreated waste (mg/l)	Treated wastewater (mg/l)	Treated nonwastewater (mg/l)
BDAT Inorganics Other Than Metals			
Cyanide (total)	12,085	<0.014	252.4
BDAT List Metals			
Copper	8,165	-	-
Nickel	138	-	-
Cadmium	128	-	-
Chromium	<116	-	-
Lead	105	-	-
Zinc	325	-	-
Non-BDAT List Metals			
Iron	248	-	-
Other Parameters			
pH	10.7	-	-
TOC	<2%	-	-

- = Not analyzed

[a] Batch consisted of a mixture of liquids and drummed solids including waste codes F007, F009, F012, and D003.

Reference: CyanoKEM 1989.

Table 4-3 (continued)

Sample Set No. 13 - for Treatment of D002

Constituent/parameter	Concentration Untreated waste (mg/l)	Treated wastewater (mg/l)	Treated nonwastewater (mg/l)
BDAT Inorganics Other Than Metals			
Cyanide (total)	10,902	0.07	203.1
BDAT List Metals			
Copper	355	-	-
Nickel	160	-	-
Cadmium	7,050	-	-
Chromium	120	-	-
Lead	125	-	-
Zinc	9,940	-	-
Non-BDAT List Metals			
Iron	1,530	-	-
Other Parameters			
pH	11.8	-	-
TOC	<2%	-	-

- = Not analyzed.

Reference: CyanoKEM 1989.

Table 4-3 (continued)

Sample Set No. 14[a] - for Treatment of F009, F011, D002, and D003

Constituent/parameter	Concentration Untreated waste (mg/l)	Treated wastewater (mg/l)	Treated nonwastewater (mg/l)
BDAT Inorganics Other Than Metals			
Cyanide (total)	16,010	0.07	94.4
BDAT List Metals			
Copper	6,272	-	-
Nickel	223	-	-
Cadmium	4,063	-	-
Chromium	133	-	-
Lead	124	-	-
Zinc	6,012	-	-
Non-BDAT List Metals			
Iron	3,511	-	-
Other Parameters			
pH	11.5	-	-
TOC	<2%	-	-

- = Not analyzed

[a] Batch consisted of a mixture of liquids and drummed solids including waste codes F009, F011, D002, and D003.

Reference: CyanoKEM 1989.

Table 4-4 Electrolytic Oxidation Treatment Data from Literature Source A for Treatment of F007 and F009 Wastes

Constituent	Concentration (units) Untreated waste (mg/l)	 Treated wastewater (mg/l)	Reaction time (days)
Sample Set #1:			
Cyanide (total)	95,000	0.1	16
Sample Set #2:			
Cyanide (total)	75,000	0.2	17
Sample Set #3:			
Cyanide (total)	50,000	0.4	10
Sample Set #4:			
Cyanide (total)	75,000	0.2	18
Sample Set #5:			
Cyanide (total)	65,000	0.2	12
Sample Set #6:			
Cyanide (total)	100,000	0.3	17
Sample Set #7:			
Cyanide (total)	55,000	0.4	14
Sample Set #8:			
Cyanide (total)	45,000	0.1	7
Sample Set #9:			
Cyanide (total)	50,000	0.4	14
Sample Set #10:			
Cyanide (total)	55,000	0.2	8
Sample Set #11:			
Cyanide (total)	48,000	0.4	12

Note: Design values for operating conditions are presented below:

Parameter	Value/Description
Temperature	200°F minimum
Total current	1,200 amp @ 6 volts
Anode current density	35 amp/ft^2

Reference: Easton 1967. Treatment of F007 and F009 copper plating wastes.

Table 4-5 High-Temperature Cyanide Hydrolysis Data from Literature Source B for Treatment of F007, F008, and F009 Wastes

	Concentration (units)		Operating Data (units)		
Constituent	Untreated waste (mg/l)	Treated wastewater (mg/l)	Maximum temperature (°F)	Maximum pressure (psi)	Reaction time at maximum temperature (hr)
Sample Set No. 1:					
Cyanide (total)	10,000	19.8	477	700	1 hr
Sample Set No. 2:					
Cyanide (total)	30,000	0.8	492	875	1 hr
Sample Set No. 3:					
Cyanide (total)	10,000	2.6	450	-[a]	1 hr
Sample Set No. 4:					
Cyanide (total)	10,000	15	460	620	1 hr
Sample Set No. 5:					
Cyanide (total)	33,000	1.2	500	875	1 hr
Sample Set No. 6:					
Cyanide (total)	38,000	2.1	458	875	1 hr

[a] Pressure gauge malfunction; 875 psi is assumed.

Reference: Robey 1983. Treatment of F007-F009 wastes containing cadmium, copper, and/or nickel cyanides.

Table 4-6 Incineration Data Submitted by Plant D for Treatment of F010 and D003

	Concentration (units)	
	Untreated waste (total) (mg/kg)	Treated nonwastewater (total) (mg/kg)
Sample Set No. 1:		
Cyanide (total)	21,000[a]	0.45
Sample Set No. 2:		
Cyanide (total)	21,000[a]	0.40
Sample Set No. 3:		
Cyanide (total)	21,000[a]	0.88

- = Not analyzed.

[a] This concentration represents the mean of two untreated waste samples, an oil contaminated with cyanide (F010/D003, 22,000 ppm) and a lacquer contaminated with cyanide (D003, 20,000 ppm).

Reference: CyanoKEM 1988.

Table 4-7 Alkaline Chlorination Data Submitted by Plant C for Various Wastes

Sample Set No. 1[a] - for Treatment of D003 and F007

Constituent/parameter	Concentration (units) Untreated waste (mg/l)	Concentration (units) Treated wastewater (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (amenable)	-	<1.0
Cyanide (total)	60,000	-
BDAT List Metals		
Cadmium	117	-
Chromium (total)	<100	-
Copper	4,000	-
Lead	<100	-
Nickel	1,500	-
Zinc	1,800	-
Non-BDAT List Metals		
Iron	1,700	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Alkaline chlorination reactor pH	12.5-13.0	12.9
Retention time for alkaline chlorination	2-6 hr minimum[b]	96 hr
ORP for alkaline chlorination	>200 mV	380 mV

- = Not analyzed.

[a] Batch consisted of a mixture of waste codes D003 and F007.

[b] Actual retention time is based on a "not detected" result for the analysis of the waste for amenable cyanide.

Reference: CyanoKEM 1987.

Table 4-7 (continued)

Sample Set No. 2[a] - for Mixed F006-F012, P030

Constituent/parameter	Concentration (units) Untreated waste (mg/l)	 Treated wastewater (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (amenable)	-	<0.1
Cyanide (total)	11,400	-
BDAT List Metals		
Cadmium	25	-
Chromium (total)	1,300	-
Copper	3,400	-
Lead	250	-
Nickel	7,300	-
Zinc	18,500	-
Non-BDAT List Metals		
Iron	3,000	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Alkaline chlorination reactor pH	12.5-13.0	12.45
Retention time for alkaline chlorination	2-6 hr minimum[b]	24 hr
ORP for alkaline chlorination	>200 mV	345 mV

- = Not analyzed.

[a] Batch consisted of a mixture of liquids and drummed solids including waste codes F006, F007, F008, F009, F011, F012, and P030.

[b] Actual retention time is based on a "not detected" result for the analysis of the waste for amenable cyanide.

Table 4-7 (continued)

Sample Set No. 3[a] - for Treatment of F007

Constituent/parameter	Concentration (units) Untreated waste (mg/l)	Treated wastewater (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (amenable)	-	<0.1
Cyanide (total)	100	-
BDAT List Metals		
Cadmium	-	-
Chromium (total)	780	-
Copper	440	-
Lead	<100	-
Nickel	1,740	-
Zinc	<100	-
Non-BDAT List Metals		
Iron	470	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Alkaline chlorination reactor pH	12.5-13.0	12.65
Retention time for alkaline chlorination	2-6 hr minimum[b]	5.5 hr
ORP for alkaline chlorination	>200 mV	350 mV

- = Not analyzed.

[a] Batch was waste code F007.

[b] Actual retention time is based on a "not detected" result for the analysis of the waste for amenable cyanide.

Table 4-7 (continued)

Sample Set No. 4[a] - for Treatment of D003

Constituent/parameter	Concentration (units) Untreated waste (mg/l)	 Treated wastewater (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (amenable)	-	<0.1
Cyanide (total)	13,000	-
BDAT List Metals		
Cadmium	-	-
Chromium (total)	-	-
Copper	<100	-
Lead	-	-
Nickel	<100	-
Zinc	-	-
Non-BDAT List Metals		
Iron	320	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Alkaline chlorination reactor pH	12.5-13.0	11.8
Retention time for alkaline chlorination	2-6 hr minimum[b]	2 hr
ORP for alkaline chlorination	>200 mV	520 mV

- = Not analyzed.

[a] Batch tested consisted of solid sodium and potassium cyanide salts of 130,000 ppm cyanide concentration (D003).

[b] Actual retention time is based on a "not detected" result for the analysis of the waste for amenable cyanide.

Table 4-7 (continued)

Sample Set No. 5[a] - for Treatment of F009

	Concentration (units)	
Constituent/parameter	Untreated waste (mg/l)	Treated wastewater (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (amenable)	-	<1.0
Cyanide (total)	27,200	-
BDAT List Metals		
Cadmium	-	-
Chromium (total)	-	-
Copper	270	-
Lead	-	-
Nickel	1,050	-
Zinc	3,070	-
Non-BDAT List Metals		
Iron	3,320	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Alkaline chlorination reactor pH	12.5-13.0	12.6
Retention time for alkaline chlorination	2-6 hr minimum[b]	20 hr
ORP for alkaline chlorination	>200 mV	460 mV

- = Not analyzed.

[a] Waste tested was F009.

[b] Actual retention time is based on a "not detected" result for the analysis of the waste for amenable cyanide.

Table 4-7 (continued)

Sample Set No. 6[a] - for Treatment of F011 and D002

	Concentration (units)	
Constituent/parameter	Untreated waste (mg/l)	Treated wastewater (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (amenable)	-	<1.0
Cyanide (total)	6,000	-
BDAT List Metals		
Cadmium	-	-
Chromium (total)	-	-
Copper	-	-
Lead	-	-
Nickel	-	-
Zinc	11,000	-
Non-BDAT List Metals		
Iron	4,000	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Alkaline chlorination reactor pH	12.5-13.0	12.8
Retention time for alkaline chlorination	2-6 hr minimum[b]	48 hr
ORP for alkaline chlorination	>200 mV	424 mV

- = Not analyzed.

[a] Batch consisted of a mixture of F011 and D002.

[b] Actual retention time is based on a "not detected" result for the analysis of the waste for amenable cyanide.

Table 4-7 (continued)

Sample Set No. 7[a] - for Treatment of F009

Constituent/parameter	Concentration (units) Untreated waste (mg/l)	 Treated wastewater (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (amenable)	-	<1.0
Cyanide (total)	30,000	-
BDAT List Metals		
Cadmium	-	-
Chromium (total)	-	-
Copper	-	-
Lead	-	-
Nickel	-	-
Zinc	19,250	-
Non-BDAT List Metals		
Iron	-	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Alkaline chlorination reactor pH	12.5-13.0	12.8
Retention time for alkaline chlorination	2-6 hr minimum[b]	12 hr
ORP for alkaline chlorination	>200 mV	400 mV

- = Not analyzed.

[a] Batch consisted of a mixture of F009 (zinc plating waste) and a waste hypochlorite solution.

[b] Actual retention time is based on a "not detected" result for the analysis of the waste for amenable cyanide.

Table 4-7 (continued)

Sample Set No. 8[a] - for Treatment of F007

	Concentration (units)	
Constituent/parameter	Untreated waste (mg/l)	Treated wastewater (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (amenable)	-	<1.0
Cyanide (total)	6,000	
BDAT List Metals		
Cadmium	-	-
Chromium (total)	<100	-
Copper	1,500	-
Lead	-	-
Nickel	-	-
Zinc	580	-
Non-BDAT List Metals		
Iron	490	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Alkaline chlorination reactor pH	12.5-13.0	12.9
Retention time for alkaline chlorination	2-6 hr minimum[b]	8 hr
ORP for alkaline chlorination	>200 mV	380 mV

- = Not analyzed.

[a] Batch was F007 waste.

[b] Actual retention time is based on a "not detected" result for the analysis of the waste for amenable cyanide.

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Table 4-8. Alkaline Chlorination Data Collected by EPA at Plant E

	Concentration (units)		
Constituent/parameter	Untreated waste (mg/l)	Treated wastewater (mg/l)	Solids residue
Sample Set No. 1			
Cyanide (total)	5,800	<5	
Sample Set No. 2			
Cyanide (total)	11,000	<5	

Source: USEPA 1985

Table 4.9 SO_2/Air Oxidation Treatment Data Submitted by Plant F

Sample Set No. 1 - for Treatment of Cyanide (Batch-Type)

Constituent/parameter	Concentration (units) Untreated waste (mg/l)	Concentration (units) Treated wastewater (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (total)	150	0.2
BDAT List Metals		
Cadmium	-	-
Chromium (total)	-	-
Copper	90	1.2
Lead		-
Nickel	-	-
Zinc	-	-
Non-BDAT List Metals		
Iron	2.8	<0.2
Other Parameters		
pH	9.5	8.5

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
SO_2 added	3-7 g SO_2/g CN_T	8.0 g SO_2/g CN_T

- = Not analyzed

Reference: Inco 1989, Appendix B.

Table 4.9 (continued)

Sample Set No. 2 for Treatment of Cyanide (Continuous-Mode)

Constituent/parameter	Concentration (units) Untreated waste (mg/l)	 Treated wastewater (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (total)	151	0.2
BDAT List Metals		
Cadmium	-	-
Chromium (total)	-	-
Copper	90	1.2
Lead	-	-
Nickel	9.7	0.2
Zinc	<0.2	<0.2
Non-BDAT List Metals		
Iron	2.8	<0.2
Other Parameters		
pH	9.5	8.5

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
SO_2 added	2-5 g/g CN_T	4.0 g/g CN_T
Cu^{2+} added	<50 mg/L Cu	0 g/g CN_T
Flow rate	-	0.1 m^3/hr
Total retention	-	60 min

- = Not analyzed

Reference: Inco 1989, Appendix C.

Table 4-9 (continued)

Sample Set No. 3 - for Treatment of Cyanide from
Plating Rinse Waters and Bleeds (Feed H Stream)

Constituent/parameter	Concentration (units) Untreated waste (mg/l)	 Treated wastewater (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (total)	62,400	12.7
BDAT List Metals		
Cadmium	-	-
Chromium (total)	-	-
Copper	3600	2.6
Lead	-	-
Nickel	5400	0.9
Zinc	-	-
Non-BDAT List Metals		
Iron	26.4	3.0
Other Parameters		
pH	13.1	9.0

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
SO_2 added	$\leq$2% SO_2/air (volume percent)	3 5 g/g CN_T
Base (NaOH) g/g CN_T		-.3
Cu^{2+} added	50 mg/l Cu	0 g/g CN_T
Retention time	-	1,200 min

= Not analyzed

Reference: Inco 1989, Appendix E.

Table 4-9 (continued)

Sample Set No. 4 - for Treatment of Cyanide from Plating Rinse Waters and Bleeds (Feed I Stream)

Constituent/parameter	Concentration (units) Untreated waste (mg/l)	 Treated wastewater (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (total)	1280	2.8
BDAT List Metals		
Cadmium	-	-
Chromium (total)	-	-
Copper	760	4.6
Lead	-	-
Nickel	2.2	<0.2
Zinc	-	-
Non-BDAT List Metals		
Iron	6.0	1.0
Tin	1500	30
Other Parameters		
pH	11.4	9.1

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
SO_2 added	$\leq$2% SO_2/air (volume percent)	4.4 g/g CN_T (stage 1) 0 g/g CN_T (stage 2)
Base (NaOH)	-	1.2 g/g CN_T (stage 1) 0 g/g CN_T (stage 2)
Cu^{2+} added	50 mg/l Cu	0 g/g CN_T (stage 1) 0 g/g CN_T (stage 2)
Retention time	-	1,000 min

- = Not analyzed

Reference: Inco 1989, Appendix E.

Table 4-9 (continued)

Sample Set No. 5 - for Treatment of Cyanide from Plating Rinse Waters and Bleeds (Feed J Stream)

	Concentration (units)	
Constituent/parameter	Untreated waste (mg/l)	Treated wastewater (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (total)	540	1.2
BDAT List Metals		
Cadmium	-	-
Chromium (total)	-	-
Copper	-	2.2
Lead	-	-
Nickel	-	-
Zinc	90	8.4
Non-BDAT List Metals		
Iron	0.2	<0.2
Other Parameters		
pH	11.3	9.0

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
SO_2 added	$\leq$2% SO_2/air (volume percent)	4.7 g/g CN_T
Base (NaOH)	-	3.5 g/g CN_T
Cu^{2+} added	50 mg/L Cu	0.09 g/g CN_T
Retention time	-	80 min

- = Not analyzed

Reference: Inco 1989, Appendix E.

Table 4-9 (continued)

Sample Set No. 6 for Treatment of Cyanide from Plating Rinse Waters and Bleeds (Feed K Stream)

Constituent/parameter	Concentration (units) Untreated waste (mg/l)	 Treated wastewater (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (total)	142	<0.4
BDAT List Metals		
Cadmium	10.0	<0.1
Chromium (total)	-	-
Copper	47.3	2.6
Lead	-	-
Nickel	-	-
Zinc	14.3	<0.1
Non-BDAT List Metals		
Iron	18.0	0.2
Other Parameters		
pH	-	9.0

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
SO_2 added	$\leq$2% SO_2/air (volume percent)	4.7 g/g CN_T 1.4 g/g CN_T
Base (Lime)	-	6.4 g/g CN_T 3.2 g/g CN_T
Cu^{2+} added	50 mg/L Cu	0 g/g CN_T 0 g/g CN_T
Retention time	-	14.4 min

- = Not analyzed

Reference: Inco 1989, Appendix E.

Table 4 9 (continued)

Sample Set No. 7 - for Treatment of Cyanide from
Plating Rinse Water (Continuous)

	Concentration (units)	
Constituent/parameter	Untreated waste (mg/l)	Treated wastewater (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (total)	142	0.88
BDAT List Metals		
Cadmium	10.0	<0.1
Chromium (total)	-	-
Copper	47.3	0.8
Lead	-	-
Nickel	0	-
Zinc	14.3	<0.05
Non-BDAT List Metals		
Iron	18.0	0.4
Other Parameters		
pH	-	10.0

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Retention time	-	36 min
Redox (S.C.E.)	-	-
SO_2 added	0.5-10 vol. % (1-3 vol % SO_2 in air is optimum)	4.69 g/g CN_T (R1) 2.35 g/g CN_T (R2) 0 g/g CN_T (effluent)
Lime added	-	6.4 g/g CN_T (R1) 3.21 g/g CN_T (R2) 0.1 g/g CN_T (effluent)

- = Not analyzed

Reference: Inco 1989, Appendix E.

Table 4-10 UV/Ozonolysis Treatment Data from Pilot Tests Submitted by Plant C

Sample Set No. 1[a] - for Treatment of F009, D003, F006, F008, D002, and P106

	Concentration (units)	
Constituent/parameter	Untreated waste (mg/l)	Treated waste (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (total)	2050	1510
BDAT List Metals		
Cadmium	-	-
Chromium (total)	-	-
Copper	35	-
Lead	-	-
Nickel	60	-
Zinc	150	-
Non-BDAT List Metals		
Iron	1400	-
Other Parameters		
pH	12.68	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Retention time	-	3.5 hr
Batch size	-	1.75 gal
Recirculation rate	-	1.7 gal/min
Operating temperature	-	73°F
Ozone feed rate	-	14 g/hr

- = Not analyzed.

[a] Batch was a mixture of F009, D003, F006, F008, D002, and P106, pretreated by alkaline chlorination.

Reference: CyanoKIM 1989.

Table 4-10 (continued)

Sample Set No. 2[a] - for Treatment of F009, D003, F006, F008, D002, and P106

Constituent/parameter	Concentration (units) Untreated waste (mg/l)	 Treated waste (mg/l)
BDAT Inorganics Other Than Metals		
Cyanide (total)	1150	800
BDAT List Metals		
Cadmium	-	-
Chromium (total)	-	-
Copper	48	-
Lead	-	-
Nickel	24	-
Zinc	180	-
Non-BDAT List Metals		
Iron	1240	-
Other Parameters		
pH	12.42	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Retention time	-	4 [illegible] hr
Batch size	-	1.75 gal
Recirculation rate	-	1.7 gal/min
Operating temperature	-	73°F
Ozone feed rate	-	14 g/hr

- = Not analyzed.

[a] Batch was a mixture of F009, D003, F006, F008, D002, and P106, pretreated by alkaline chlorination.

Reference: CyanoKEM 1989.

Table 4-11 Stabilization Treatment Data for Aluminum Coil Plating Sludge Collected by EPA

Sample Set No. 1

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg/L)			
		#1	#2	#3	#4
Arsenic	18.9	<0.005	<0.005	0.0088	<0.0002
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	0.060	0.051	<0.08	<0.08
Copper	4,700	-	-	-	-
Lead	42.4	<0.001	<0.001	<0.6	<0.6
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.001	<0.001	<1.44	<0.48
Cyanide (total)	1,955	5.77	3.43	5.50	5.75

Other Parameters

Parameter	Untreated waste	Treated waste
pH	7.3	8.7
Average U.C.S. (kPa)	-	1,367
Total solids (%, w/ww)	28.45	89.9
Bulk density (g/cm^3)	1.2	-
Specific gravity	-	2.30

- = Not analyzed.
Reference: USEPA 1988g.

Table 4-11 (continued)

Sample Set No. 2

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg/L)			
		#1	#2	#3	#4
Arsenic	18.9	<0.005	<0.005	0.001	0.0036
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	1.92	1.91	11	9.9
Copper	4,700	-	-	-	-
Lead	42.4	<0.001	<0.001	<0.002	<0.002
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.001	<0.001	<0.1	<0.1
Cyanide (total)	1,955	5.1	4.29	1.878	1.774

Other Parameters

Parameter	Untreated waste	Treated waste
pH	7.3	10.64
Average U.C.S. (kPa)	-	1,355
Total solids (%, w/ww)	28.45	64.29
Bulk density (g/cm^3)	1.2	1.35
Specific gravity	-	2.49

- = Not analyzed

Reference: USEPA 1988g.

Table 4-11 (continued)

Sample Set No. 3

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg/l)			
		#1	#2	#3	#4
Arsenic	18.9	<0.005	<0.005	<0.005	<0.005
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	0.015	0.014	0.019	0.018
Copper	4,700	-	-	-	-
Lead	42.4	<0.001	<0.001	<0.001	<0.001
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.001	<0.001	<0.001	<0.001
Cyanide (total)	1,955	6.3	6.62	6.45	6.56

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg/l)			
		#5	#6	#7	#8
Arsenic	18.9	<0.005	<0.005	0.0021	0.0022
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	0.014	0.012	<0.08	<0.08
Copper	4,700	-	-	-	-
Lead	42.4	<0.001	<0.001	<0.6	<0.6
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.001	<0.001	<0.48	<0.48
Cyanide (total)	1,955	6.60	6.59	7.8	7.5

Other Parameters

Parameter	Untreated waste	Treated waste
pH	7.3	10.6
Average U.C.S. (kPa)	-	16.023
Total solids (%, w/ww)	28.45	81.84
Bulk density (g/cm^3)	1.2	2.0
Specific gravity	-	2.32

- = Not analyzed

Reference: USEPA 1988g.

Table 4-11 (continued)

Sample Set No. 4

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg			
		#1	#2	#3	#4
Arsenic	18.9	<0.001	<0.001	0.0011	0.0009
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	0.177	0.190	<0.08	<0.08
Copper	4,700	-	-	-	-
Lead	42.4	0.005	0.004	<0.6	<0.5
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.02	<0.02	<0.48	<0.48
Cyanide (total)	1,955	34.3	34.2	24.8	24.3

Other Parameters

Parameter	Untreated waste	Treated waste
pH	7.3	8.7
Average U.C.S. (kPa)	-	-
Total solids (%, w/ww)	28.45	-
Bulk density (g/cm^3)	1.2	1.34
Specific gravity	-	2.24

- = Not analyzed
Reference: USEPA 1988g.

Table 4-11 (continued)

Sample Set No. 5

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg/L)			
		#1	#2	#3	#4
Arsenic	18.9	<0.001	0.03	0.0008	0.0006
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	0.210	0.121	<0.08	<0.08
Copper	4,700	-	-	-	-
Lead	42.4	<0.001	<0.001	<0.6	<0.6
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.02	<0.02	<0.48	<0.48
Cyanide (total)	1,955	25.6	24	23	22.8

Other Parameters

Parameter	Untreated waste	Treated waste
pH	7.3	8.3
Average U.C.S. (kPa)	-	-
Total solids (%, w/ww)	28.45	-
Bulk density (g/cm^3)	1.2	-
Specific gravity	-	2.67

- = Not analyzed
Reference: USEPA 1988g.

Table 4-11 (continued)

Sample Set No 6

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg/l)			
		#1	#2	#3	#4
Arsenic	18.9	0.004	0.004	<0.0002	0.0004
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	0.022	0.016	<0.08	<0.08
Copper	4,700	-	-	-	-
Lead	42.4	<0.002	<0.002	<0.6	<0.6
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.1	<0.1	<0.48	<0.48
Cyanide (total)	1,955	1.515	3.018	5.0	5.4

Other Parameters

Parameter	Untreated waste	Treated waste
pH	7.3	6.6
Average U.C.S. (kPa)	-	-
Total solids (%, w/ww)	28.45	-
Bulk density (g/cm^3)	1.2	1.41
Specific gravity	-	2.73

- = Not analyzed

Reference: USEPA 1988g.

Table 4-11 (continued)

Sample Set No. 7

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg/l)			
		#1	#2	#3	#4
Arsenic	18.9	0.0072	0.006	0.0004	0.0005
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	0.303	0.246	<0.08	<0.08
Copper	4,700	-	-	-	-
Lead	42.4	<0.001	0.001	<0.6	<0.6
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.02	<0.02	<0.48	<0.48
Cyanide (total)	1,955	3.25	3.31	2.30	2.0

Other Parameters

Parameter	Untreated waste	Treated waste
pH	7.3	9.49
Average U.C.S. (kPa)	-	-
Total solids (% w/ww)	28.45	-
Bulk density (g/cm^3)	1.2	1.38
Specific gravity	-	2.46

- = Not analyzed
Reference: USEPA 1988g

Table 4-11 (continued)

Sample Set No. 8

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg/l)			
		#1	#2	#3	#4
Arsenic	18.9	<0.005	<0.005	<0.005	<0.005
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	0.319	0.373	0.315	0.396
Copper	4,700	-	-	-	-
Lead	42.4	<0.001	<0.001	<0.001	<0.001
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.001	<0.001	<0.001	<0.001
Cyanide (total)	1,955	2.71	2.77	2.86	2.85

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg/l)			
		#5	#6	#7	#8
Arsenic	18.9	<0.005	<0.005	0.033	0.028
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	0.326	0.263	5.3	5.8
Copper	4,700	-	-	-	-
Lead	42.4	<0.001	<0.001	0.002	0.002
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.001	<0.001	<0.02	<0.02
Cyanide (total)	1,955	2.9	2.94	1.25	1.15

Other Parameters

Parameter	Untreated waste	Treated waste
pH	7.3	5.52
Average U.C.S. (kPa)	-	-
Total solids (%, w/ww)	28.45	98.69
Bulk density (g/cm^3)	1.2	1.13
Specific gravity	-	2.55

- = Not analyzed

Reference: USEPA 1988g.

Table 4-11 (continued)

Sample Set No. 9

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg/l)			
		#1	#2	#3	#4
Arsenic	18.9	<0.005	<0.005	<0.005	<0.005
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	0.009	0.007	0.008	0.004
Copper	4,700	-	-	-	-
Lead	42.4	<0.001	<0.001	<0.001	<0.001
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.001	<0.001	<0.001	<0.001
Cyanide (total)	1,955	13.9	13.3	14.2	13.4

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg/l)			
		#5	#6	#7	#8
Arsenic	18.9	<0.005	<0.005	0.001	0.0009
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	0.004	0.003	<0.08	<0.08
Copper	4,700	-	-	-	-
Lead	42.4	<0.001	<0.001	<0.6	<0.6
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.001	<0.001	<0.48	<0.48
Cyanide (total)	1,955	12.6	12.2	7.8	8.0

Other Parameters

Parameter	Untreated waste	Treated waste
pH	7.3	8.49
Average U.C.S. (kPa)	-	-
Total solids (%, w/ww)	28.45	64.48
Bulk density (g/cm^3)	1.2	1.46
Specific gravity	-	2.25

- = Not analyzed

Reference: USEPA 1988g.

Table 4-11 (continued)

Sample Set No. 10

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg/l)			
		#1	#2	#3	#4
Arsenic	18.9	<0.005	<0.005	<0.005	<0.005
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	0.089	0.091	0.096	0.093
Copper	4,700	-	-	-	-
Lead	42.4	<0.001	<0.001	<0.001	<0.001
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.001	<0.001	<0.001	<0.001
Cyanide (total)	1,955	12.4	12.7	11.8	12.1

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg/l)			
		#5	#6	#7	#8
Arsenic	18.9	<0.005	<0.005	0.0007	0.0008
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	0.085	0.095	<0.08	<0.08
Copper	4,700	-	-	-	-
Lead	42.4	<0.001	<0.001	<0.6	<0.6
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.001	<0.001	<0.48	<0.48
Cyanide (total)	1,955	12.1	12.7	9.0	9.5

Other Parameters

Parameter	Untreated waste	Treated waste
pH	7.3	9.67
Average U.C.S. (kPa)	-	-
Total solids (%, w/ww)	28.45	68.94
Bulk density (g/cm^3)	1.2	1.27
Specific gravity	-	2.41

- = Not analyzed

Reference: USEPA 1988g

Table 4-11 (continued)

Sample Set No. 11

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg/l)			
		#1	#2	#3	#4
Arsenic	18.9	<0.001	<0.001	0.0007	0.0006
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	0.155	0.092	<0.08	<0.08
Copper	4,700	-	-	-	-
Lead	42.4	<0.001	<0.001	<0.6	<0.6
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.02	<0.02	<0.48	<0.48
Cyanide (total)	1,955	5.41	5.69	3.5	11.25

Other Parameters

Parameter	Untreated waste	Treated waste
pH	7.3	9.72
Average U.C.S. (kPa)	-	-
Total solids (%, w/ww)	28.45	-
Bulk density, (g/cm^3)	1.2	1.48
Specific gravity	-	2.64

- = Not analyzed.
Reference: USEPA 1988g.

Table 4-11 (continued)

Sample Set No. 12

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg/L)			
		#1	#2	#3	#4
Arsenic	18.9	0.0025	<0.001	0.0004	<0.0003
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	0.115	0.096	<0.08	<0.08
Copper	4,700	-	-	-	-
Lead	42.4	<0.001	<0.001	<0.6	<0.6
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.02	<0.02	<0.48	<0.48
Cyanide (total)	1,955	10.2	10.5	7.3	7.5

Other Parameters

Parameter	Untreated waste	Treated waste
pH	7.3	8.58
Average U.C.S. (kPa)	-	-
Total solids (%, w/ww)	28.45	-
Bulk density (g/cm^3)	1.2	1.23
Specific gravity	-	2.56

- = Not analyzed.
Reference: USEPA 1988g.

Table 4-11 (continued)

Sample Set No 13

Constituent	Untreated waste (total) (mg/kg)	Treated waste TCLP (mg/L)			
		#1	#2	#3	#4
Arsenic	18.9	<0.005	<0.005	<0.0005	0.0005
Barium	3.3	-	-	-	-
Cadmium	1.6	-	-	-	-
Chromium	1,900	0.047	0.024	<0.08	<0.08
Copper	4,700	-	-	-	-
Lead	42.4	<0.001	<0.001	<0.6	<0.6
Mercury	0.1	-	-	-	-
Nickel	5.9	-	-	-	-
Thallium	25.6	<0.001	<0.001	<0.48	<0.48
Cyanide (total)	1.955	13.5	14.3	10.2	10.2

Other Parameters

Parameter	Untreated waste	Treated waste
pH	7.3	10.3
Average U.C.S. (kPa)	-	-
Total solids (%, w/ww)	28.45	43.89
Bulk density (g/cm^3)	1.2	1.21
Specific gravity	-	2.59

- = Not analyzed.
Reference: USEPA 1988g.

Table 4.12. Treatment of Cyanide-Containing Wastewaters by Chemical Precipitation

	Concentration					
	Sample 1		Sample 2		Sample 3	
Constituent	Untreated waste (mg/l)	Treated waste (mg/l)	Untreated waste (mg/l)	Treated waste (mg/l)	Untreated waste (mg/l)	Treated waste (mg/l)
Cyanide (total)	2.5	0.024	2.42	0.015	3.28	0.031

Treatment consists of precipitation of ferrocyanide by addition of ferrous sulfate, followed by sedimentation and removal of precipitate.

Data are from Plant # 01057

Reference: USEPA 1983.

Table 4-1[illegible] Treatment of Cyanide-Containing Wastewaters by Ozonation

Constituent	Concentration					
	Day 1		Day 2		Day 3	
	Untreated waste (mg/l)	Treated waste (mg/l)	Untreated waste (mg/l)	Treated waste (mg/l)	Untreated waste (mg/l)	Treated waste (mg/l)
Cyanide (amenable)	1 4	110	30	039	2 389	096
Cyanide (total)	1 4	113	30	039	2 4	096

Treatment consists of contacting [illegible] moles of ozone per mole of cyanide at a pH of 9 0-9 5

Data are from Plant # 30022, a plant that electroplates gold, silver, copper, and nickel for the electronics industry.

Reference: USEPA 1983

Table 4.14 Treatment of Cyanide-Containing Wastewaters by Alkaline Chlorination

Plant ID	Cyanide (amenable)			Cyanide (total)		
	Treated waste concentration (mg/l)	Dilution factor	Adjusted concentration (mg/l)	Treated waste concentration (mg/l)	Dilution factor	Adjusted concentration (mg/l)
12065	0	[illegible]	0	.014	10	.14
21051	0	[illegible]	0	0	1	0
21051	0	[illegible]	0	0	1	0
21051	0	[illegible]	0	0	1	0
36051	0	[illegible]	0	0	19.9	0
06075	.005	[illegible]	.025	.005	5	.025
06075	.005	[illegible]	.024	.005	4.8	.024
06075	-		-	.014	4.8	.067
36623	.005	[illegible]	.025	.033	5.1	.167
36623	.005	[illegible]	.024	.02	4.9	.098
36623	.005	[illegible]	.021	.01	4.3	.043
19050	.005	[illegible]	.031	.005	6.2	.031
20079	.005	[illegible]	.039	.005	7.9	.039
20079	.005	[illegible]	.031	.005	6.2	.031
20079	.005	[illegible]	.030	.005	6.1	.031
20079	.005	[illegible]	.028	.02	5.6	.112
20079	.005	[illegible]	.025	21.0	5.0	105*
20079	.005	[illegible]	.024	.005	4.8	.024
05021	.005	[illegible]	.04	.007	8	.056
05021	.005	[illegible]	.024	.005	4.8	.024
05021	.005	[illegible]	.024	.005	4.8	.024
20078	.01	[illegible]	.066	.04	6.6	.266
20078	.005	[illegible]	.037	.005	7.4	.037
20078	.005	[illegible]	.035	.005	7.0	.035
20078	.005	[illegible]	.034	.01	6.9	.069
20078	.005	[illegible]	.029	.005	5.7	.029
20078	.005	[illegible]	.028	.005	5.6	.028
15070	.02	[illegible]	.068	.03	3.4	.102
15070	.005	[illegible]	.014	.29	2.8	.818
15070	.005	[illegible]	.012	.02	2.5	.05
33073	.027	[illegible]	.147	.254	5.5	1.39
33073	.008	[illegible]	.041	.129	5.1	.66
33073	-		-	.013	5.5	.071
09026	.06	[illegible]	.156	.08	2.6	.208
09026	.01	[illegible]	.024	.03	2.4	.072
09026	.005	[illegible]	.021	.02	3.8	.076

Table 4-14 (continued)

Plant ID	Cyanide (amenable) Treated waste concentration (mg/l)	Dilution factor	Adjusted concentration (mg/l)	Cyanide (total) Treated waste concentration (mg/l)	Dilution factor	Adjusted concentration (mg/l)
31021	05	[illegible]	16	16	3 2	5.12
31021	05	[illegible]	16	16	3 2	5.12
31021	.05	[illegible]	15	.35	3.1	[illegible]
33024	04	[illegible]	204	04	5 1	204
20080	104	4	416	111	4 0	444
20080	005	5.8	029	005	5 8	029
20080	.005	4.5	023	.005	4.5	.023
20080	005	4.5	023	.005	4 5	.023
20080	005	4.5	023	.005	4 5	023
20080	-		-	1	4 1	41
20080	-		-	1.23	4.6	5.69*

Notes

Treatment consists of a two-step process resulting in oxidation of cyanide to carbon dioxide and nitrogen. In the first step, cyanide is oxidized to cyanate by the addition of chlorine at a pH of 9.5-10. In the second step, cyanate is oxidized to carbon dioxide and nitrogen at a pH of [illegible]

Treated waste concentration - the measured concentration of the final effluent after treatment. At this point, cyanide wastes are mixed with other wastewaters.

Dilution factor - the amount of dilution of the cyanide raw waste stream by other raw waste streams. It is determined by dividing the total effluent stream flow by the cyanide stream flow.

Adjusted concentration - product of treated waste concentration and dilution factor.

Table includes data only from plants considered by the Agency to be well designed and well operated.

*Data should not be used. The 105 mg/l point should not be used because it is a high outlier. The 5.69 mg/l point should not be used because it is a high outlier and because there is no corresponding amenable cyanide point.

Influent (raw waste) concentrations are not given in the table. However, no data point is listed in the table unless the influent concentration exceeded the effluent concentration.

Reference: USEPA 1983

5. IDENTIFICATION OF BEST DEMONSTRATED AVAILABLE TECHNOLOGY (BDAT)

This section presents the Agency's rationale for determining best demonstrated available technology (BDAT) for F006 (cyanide) nonwastewaters and F007 through F012 nonwastewaters and wastewaters. To determine BDAT, the Agency examines all available performance data for the technologies that are identified as demonstrated to determine whether one of these technologies performs significantly better than the others. All performance data used for determination of best technology must first be adjusted for accuracy, as discussed in EPA's publication Methodology for Developing BDAT Treatment Standards.* BDAT must be specifically defined for all streams associated with the management of the listed waste or wastes; this includes the original waste as well as any residual waste streams created by the treatment process.

The technology that performs best on a particular waste or waste subcategory is then evaluated to determine whether it is "available." To be available, the technology must (1) be commercially available to any generator and (2) provide "substantial" treatment of the waste, as determined through evaluation of accuracy-adjusted data. In determining whether treatment is substantial, EPA may consider data on the performance of a waste similar to the waste in question, provided that the similar waste is at least as difficult to treat.

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*Accuracy adjustment accounts for the ability of an analytical technique to recover a particular constituent from the waste in a particular test. The recovery of a constituent is determined by spiking a sample with a known amount of the target constituent and then comparing the result of analysis of the spiked sample with the result from the unspiked sample.

5.1 Wastes from Electroplating Operations: F006, F007, F008, and F009

5.1.1 Cyanide Treatment

EPA reviewed the available treatment performance data for all wastes generated from electroplating operations for cyanide treatment technologies, presented in Section 4, to determine whether they represent the operation of well-designed and well-operated systems, whether sufficient quality assurance/quality control (QA/QC) data were collected to assess the accuracy of the treated waste analyses, and whether the data presented provide the appropriate measure of performance for the technology tested.

The treatment performance data for wet air oxidation of F007 waste, presented in Table 4-2, provide amenable and total cyanide concentrations in the untreated waste and in both wastewater and nonwastewater residuals. The F007 waste tested had concentrations of total BDAT metals and total and amenable cyanide similar to the concentrations of these constituents found in other F007 wastes and in F008, F009, and F011 wastes (see Section 2.3 and Appendix B). Design and operating data collected during the test indicate that the system was well designed and well operated during the collection of five of the six sets of performance data. The appropriate QA/QC data were supplied with these performance data. The data collected for Sample Set No. 1 show higher concentrations of both amenable and total cyanide in the feed (approximately 20 percent higher) than for any of the other five sample sets, without a corresponding increase in residence time. This may account for poorer system performance, as shown by the data. This problem might have been alleviated in operation either by better mixing the feed or by increasing the residence time (i.e., by decreasing the feed flow rate for higher concentration feed streams). The data for Sample Set No. 1 were not considered further in the development of BDAT standards on the basis of poor system operation (insufficient reactor residence time) at the time of treatment data collection. The data on the composition of the nonwastewater residuals were not considered in further development of nonwastewater treatment standards for these waste codes. These data represent the composition of solids precipitated on the wet air oxidation reactor and thus are not directly comparable to data representing the composition of wastewater treatment sludges that may be generated following wet air oxidation or other cyanide treatment.

Treatment performance data for alkaline chlorination submitted by Plant C during the public comment period are presented in Table 4-3. These data provide total cyanide concentration in the untreated waste and the treated wastewater and nonwastewater. These data represent treatment of F006-F009, F011, F012, and other metal finishing wastes, both nonwastewater and wastewater. This facility also supplied information on the volumes of cyanide and noncyanide wastes treated so that the data submitted could be adjusted to take into account the dilution caused by addition of the noncyanide wastes (e.g., chromium and acid wastes) that are first treated separately and then combined with the cyanide wastes prior to chemical precipitation treatment. For one data point from Sample Set No. 14, insufficient information was available to correct the treated nonwastewater cyanide concentration for this dilution. Therefore, this data point was not considered further for wastewaters. For another data point from Sample Set No. 11, data supplied by the commenter indicate that poor treatment system operation allowed an unusually high cyanide concentration in the wastewater residual. This data point was not considered further for regulation of cyanide in wastewaters. With the exception of these two data points, the design and operating data submitted indicate that the system was well designed and well operated during the tests. QA/QC data are provided.

Additional treatment performance data for the same system were presented in Table 4-3 of the background document for the proposed rule. These data, presented in Table 4-7 of this document, provide total cyanide concentration in the untreated waste and amenable cyanide concentration in the treated wastewater. No grab sample data on the treated nonwastewater and insufficient QA/QC data were provided; therefore, these data were not used in the development of BDAT standards for the electroplating wastewaters.

Treatment performance data for electrolytic oxidation were obtained from literature source A and are presented in Table 4-4. These data provide total cyanide concentrations for both the untreated waste and the treated wastewater. The design values given indicate that the system was well designed, and the treated waste cyanide concentration, as well as the reaction time, indicate that the system was well operated at the time of treatment data collection. No QA/QC data were available for these tests. Also, data for nonwastewaters were not presented.

Treatment performance data for high temperature cyanide hydrolysis were obtained from literature source B and are presented in Table 4-5. These data provide total cyanide concentrations for both the untreated waste and the treated wastewater after subsequent chemical precipitation treatment followed by filtration to remove suspended precipitated solids. No system design data were specified. The operating data provided indicate that the system was well operated during the collection of treatment data sets Nos. 2, 3, 5, and 6. For data sets No. 1 and No. 4, the operating data indicate that low reactor pressure (700 psi and 620 psi versus 875 psi for the other four runs) contributed to the higher effluent cyanide concentration; therefore, these data sets were not further considered in assessing the performance of this technology (based on poor operation). No QA/QC data were given for these tests.

Treatment performance data for SO_2/air oxidation from various literature sources, submitted to the Agency during the comment period, are presented in Table 4-9. These data show total cyanide concentration in the untreated waste and the treated wastewater for seven sets of data for treatment of electroplating wastewaters. QA/QC data were requested by the Agency, but have yet to be submitted by the company. The commenter also did not present data on the composition of the nonwastewater treatment residual for any of these tests.

The treatment performance data for the demonstrated cyanide treatment technologies presented in Section 4 were adjusted for analytical recovery to take into account analytical interferences associated with the chemical makeup of the treated waste samples. In the QA/QC test for analytical recovery, EPA first analyzes a waste for a constituent and then adds a known amount (i.e., a spike) of the same constituent to the waste material and reanalyzes the sample for that constituent. The difference between the total amount detected after spiking and the concentration detected in the unspiked sample divided by the amount of spike added is the recovery value. (If recovery tests are run in duplicate, EPA uses the lower recovery value.) The reciprocal of the recovery multiplied by the analytical value obtained during performance testing is the accuracy-corrected value used in comparing treatment effectiveness and subsequently in calculating treatment standards. Percent recovery values for constituents detected in the wastes tested in the wet air oxidation and alkaline chlorination tests are presented in Appendix A. In the cases for which no analytical recovery data were available (Tables 4-4, 4-5, and 4-9), EPA believes that QA/QC adjustment of the data was not performed. Therefore, the Agency cannot directly compare these data to the data for which accuracy correction factors are available. The data presented in Tables 4-4, 4-5, and 4-9 for electrolytic oxidation, high temperature cyanide hydrolysis, and

SO_2/air oxidation, respectively, were not considered in the determination of "best" treatment of cyanide in F007-F009 wastewaters and nonwastewaters.

(1) Wastewaters. Accuracy-adjusted cyanide concentrations for all data considered in developing BDAT cyanide standards for the F007, F008, and F009 waste codes for wastewaters are presented in Tables 5-1 and 5-2 for total and amenable cyanide, respectively. (All tables are at the end of the section.) The Agency considered the data on treated wastewaters presented in Tables 4-2 and 4-3 in development of BDAT treatment standards for these wastes. Statistical comparison of the 13 data sets from alkaline chlorination with the 5 data sets from wet air oxidation from treatment of similar wastes shows that the performance of alkaline chlorination is better for treatment of total cyanide. No data are available for amenable cyanide concentration in the treated waste from the alkaline chlorination treatment system (see Table 4-3).

EPA's determination that substantial treatment occurs for alkaline chlorination is based on the reduction in total cyanide concentration in the waste tested. In addition to providing substantial treatment, alkaline chlorination is commercially available; therefore, this technology is "available" to treat cyanide in F007, F008, and F009 wastes.

(2) Nonwastewaters. Accuracy-adjusted cyanide concentrations for all data considered in developing BDAT cyanide standards for the F006, F007, F008, and F009 waste codes for nonwastewaters are presented in Table 5-3. EPA received data during the public comment period from

commercial cyanide treatment that involved treating F006, F007, F008, F009, F011, and F012 wastes. Although the relative proportion of F006 wastes in these data was small (approximately 2 percent by volume), EPA has evaluated these data carefully and believes that they are representative of treatment performance for F006 nonwastewaters, as well as for F007, F008, and F009 wastes. As explained in more detail elsewhere in this document, this is because the wastes treated are as difficult or more difficult to treat than F006-F009 wastes or F006 precursor wastewaters would be if treated separately. The basis for this conclusion is comparison of untreated waste concentrations of cyanide and of the complexing metals iron, nickel, zinc, and copper. Concentrations of these key parameters are as high (or higher) in the waste from the commercial treatment facility (see Table 4-3) as in F007-F009 wastes and F006 precursor wastestreams (see Table 2-3 for data on the composition of F006 precursor wastewaters).

F006 waste, as defined by its listing, is generated from chemical precipitation treatment, which usually follows a cyanide oxidation step if the waste treated originally contained cyanide. Thus, treatment of the waste for cyanide before generation of these wastes is the Agency's "best" technology for determination of cyanide treatment standards for F006 nonwastewaters and the nonwastewater treatment residuals from treatment of F007-F009 wastes and similar wastes. The cyanide oxidation technologies (e.g., alkaline chlorination) are also applicable to be used for further treatment of the wastewater treatment sludges prior to the dewatering steps; therefore, these wastes could be slurried with water and then treated by the BDAT technologies (as is demonstrated by the treatment data presented in Table 4-3). While the Agency does not believe that slurrying these wastes is necessarily the most cost-effective way to perform alkaline chlorination (or other cyanide treatment), this treatment option is available. In addition, generators of these sludges need not dewater them but rather may send the high-water content sludges to alkaline chlorination. In either of these situations, cyanide treatment would be performed on the listed waste itself.

As discussed in Section 4 and previously in this section, alkaline chlorination, chemical precipitation, filtration, and sludge dewatering are commercially available technologies for the treatment of F006-F009 and similar wastes and thus are "available" to be used in treatment of cyanide-containing wastes prior to generation of F006 and similar wastes.

Also, as shown in Table 4-3, the treatment train discussed above substantially reduces the concentration of cyanide in F006 waste compared to the concentration in the waste from which it was generated. Stabilization treatment of the treatment sludges generated by chemical precipitation has been shown previously, in the case of F006, to result in substantial reductions in leachate concentrations of BDAT list metals. Therefore, the treatment train discussed above, followed by stabilization of the F006 or similar waste thus generated, is "available" and thus is BDAT for F006 and is the basis for cyanide standards for wastewater treatment sludge residuals from the treatment of F007, F008, and F009 wastes.

5.1.2 BDAT List Metals Treatment

Characterization data for F007, F008, and F009 wastes show that these wastes may contain high concentrations of dissolved metals and therefore may require treatment by chemical precipitation followed by filtration and sludge dewatering. Chromium reduction may also be necessary prior to chemical precipitation if the waste has a treatable concentration of hexavalent chromium following cyanide oxidation. This treatment train can be added after application of one of the demonstrated technologies for cyanide removal, and it results in a wastewater and nonwastewater treatment residual.

(1) Wastewaters. Data on the performance of chromium reduction followed by chemical precipitation and filtration for wastewaters were developed for regulation of K062 waste. Two data sets were also presented, in Table 4-1, for chemical precipitation followed by filtration and sludge dewatering treatment of F011 waste mixed with heat treating rinsewaters. These two sets of performance data are not directly comparable because the K062 waste treated had significantly higher concentrations of BDAT list metals (approximately 100,000 ppm) than the metal heat treating wastes tested. The treatment data used in regulation of K062 can be transferred to the wastewater residual from treatment of F007, F008, and F009 because the dissolved metals concentrations of these wastes are similar to or lower than those of K062; thus, these wastes will treat similarly to K062, whereas the F011

treatment data represent treatment of a waste with significantly lower metals concentrations than expected for most F007, F008, and F009 wastes and thus cannot be transferred. Because the K062 treatment data are the only data available to EPA on the performance level of chemical precipitation and filtration treatment of a waste with high BDAT metals concentration, the Agency has determined that the performance of chemical precipitation and filtration is "best" for treatment of BDAT list metals in these wastes following cyanide treatment. As was presented for K062 (see EPA's BDAT Background Document for K062), this technology is "available" and thus meets the Agency's criteria for BDAT.

(2) Nonwastewaters. EPA has previously promulgated treatment standards for BDAT list metal constituents for F006 based on the performance of stabilization (see EPA's BDAT Background Document for F006). EPA believes that the nonwastewater treatment residuals from treatment of F007-F009 wastes by chemical precipitation followed by filtration are similar to F006 both in waste composition and in the process generating the waste. Also, substances such as oil and grease or sulfates that interfere with stabilization are not expected to be present in significant concentrations in these wastes. It follows, therefore, that since no data on treatment of F006 or similar wastes are available other than the data used to develop stabilization treatment standards for F006, stabilization represents the best treatment for BDAT list metals for F006 and the nonwastewater residuals (i.e., wastewater treatment sludges) from chemical precipitation and sludge dewatering treatment of

F007, F008, and F009 based on the similarities discussed above between F006 and these wastes.

5.2 Metal Heat Treating Wastes: F011 and F012

5.2.1 Cyanide Treatment

EPA reviewed the available treatment performance data for wastes generated in metal heat treating operations for cyanide treatment technologies, presented in Section 4, to determine whether they represent the operation of well-designed and well-operated systems, whether sufficient quality assurance/quality control (QA/QC) data were collected to assess the accuracy of the treated waste analyses, and whether the data presented provide the appropriate measure of performance for the technology tested. The treatment performance data for electrolytic oxidation followed by alkaline chlorination of F011 waste and heat treating quenching wastewaters collected at Plant presented in Table 4-1, provide the appropriate measure of performance for this technology (amenable and total cyanide concentrations in the untreated waste and in both the wastewater and nonwastewater residuals). Design and operating data collected during the test indicate that the system was well designed and well operated during the test. Additionally, the appropriate QA/QC data were supplied with these performance data.

EPA also considered all data that were considered for regulation of the electroplating waste codes (F006-F009), as identified in Section 5.1.1, as also representing treatment of the wastes generated in metal heat treating operations. This is because the information that the

Agency has about the processes generating these wastes (see Section 2) and the available waste characterization data (summarized in Section 2.3 and presented in Appendix B) indicate that the wastes generated in electroplating operations are at least as difficult to treat, in terms of concentration of complexed cyanide and iron and other complexing metals, as the wastes generated in metal heat treating operations. Wastes from metal heat treating operations are expected to contain mostly the soluble cyanide salts (such as sodium cyanide and potassium cyanide).

(1) Wastewaters. Accuracy-adjusted cyanide concentrations for all data considered in developing BDAT cyanide standards for F011 and F012 wastes for wastewaters are presented in Tables 5-4 and 5-5 for total and amenable cyanide, respectively. The Agency considered the data on treated wastewaters presented in Tables 4-1 and 4-3 in development of BDAT treatment standards for these wastes. (The data on alkaline chlorination, as presented in Table 4-3, have previously been shown to represent better treatment than the data on wet air oxidation, as presented in Table 4-2, for similar wastes.) Statistical comparison of the 13 data sets from alkaline chlorination with the 2 data sets from electrolytic oxidation followed by alkaline chlorination shows that the performance of alkaline chlorination alone is better for treatment of total cyanide. No data are available for amenable cyanide concentration in the treated waste from the alkaline chlorination treatment system (see Table 4-3).

EPA's determination that substantial treatment occurs for alkaline chlorination is based on the reduction in total cyanide concentration in the waste tested. In addition to providing substantial treatment, alkaline chlorination is commercially available; therefore, this technology is "available" to treat cyanide in the metal heat treating wastewaters (waste codes F011 and F012).

(2) Nonwastewaters. Accuracy-adjusted cyanide concentrations for all data considered in developing BDAT cyanide standards for F011 and F012 wastes for nonwastewaters are presented in Table 5-6. The Agency considered two data sets on the generation of F012 waste from a well-designed and well-operated treatment system consisting of electrolytic oxidation followed by alkaline chlorination, chemical precipitation, filtration, and sludge dewatering (presented in Table 4-1). The Agency also considered 13 data sets from treatment of mixed electroplating and metal heat treating waste in development of these standards. Statistical comparison of the two data sets from electrolytic oxidation followed by alkaline chlorination with the 13 data sets from alkaline chlorination alone shows that the performance of electrolytic oxidation followed by alkaline chlorination is better for treatment of total cyanide. No data are available for amenable cyanide concentration in the treated waste from the alkaline chlorination treatment system (see Table 4-3).

Treatment of the waste for cyanide before generation of these wastes is the Agency's "best" technology for determination of cyanide treatment standards for F012 and similar wastes. The cyanide oxidation technologies are also applicable to be used for further treatment of the wastewater treatment sludges prior to the dewatering steps; therefore, these wastes could be slurried with water and then treated by the BDAT technologies. While the Agency does not believe that slurrying these wastes is necessarily the most cost-effective way to perform alkaline chlorination (or other cyanide treatment), this treatment option is available. In addition, generators of these sludges need not dewater them but rather may send the high-water content sludges to alkaline chlorination. In either of these situations, cyanide treatment would be performed on the listed waste itself.

As discussed in Section 4 and previously in this section, alkaline chlorination, electrolytic oxidation, chemical precipitation, filtration, and sludge dewatering are commercially available technologies for the treatment of F007-F009, F011, and similar wastes and thus are "available" to be used in treatment of cyanide-containing wastes prior to generation of F012 and similar wastes.

Also, as shown in Table 4-1, the treatment train discussed above substantially reduces the concentration of cyanide in F012 waste compared to the waste from which it was generated. Stabilization treatment of the treatment sludges generated by chemical precipitation has been shown previously, in the case of F006, to result in substantial reductions in leachate concentrations of BDAT list metals. Therefore, the treatment train discussed above, followed by stabilization of the F012 or similar waste thus generated, is "available" and thus is BDAT for F012 and is the basis for cyanide standards for wastewater treatment sludge residuals from the treatment of F011 wastes.

Alternatively, the Agency believes that the cyanide treatment standards for this subcategory can be achieved by treatment of these wastes by well-designed and well-operated alkaline chlorination treatment alone. The only data for alkaline chlorination considered by the Agency in development of these standards (i.e., the only data that included design and operating and QA/QC information) were derived from treatment of mixed metal finishing wastewaters. The waste codes F011 and F012 composed only 10 percent of the wastes treated in this test. Approximately 50 percent of these wastes were waste codes F006-F009. EPA believes that the electrolytic oxidation treatment step in the BDAT treatment train specified above is essentially a "pretreatment" step that lowers the cyanide concentration of the waste fed to alkaline chlorination. The primary purpose of this step is to reduce the demand for alkaline chlorination treatment chemicals, thereby reducing the cost of treatment. In the absence of data on alkaline chlorination of metal heat treating wastes alone, the Agency thus believes that the data presented for electrolytic oxidation followed by alkaline chlorination are indicative of the performance achievable for alkaline chlorination alone, without the pretreatment step.

5.2.2 BDAT List Metals Treatment

EPA has previously promulgated treatment standards for BDAT list metal constituents for F006 based on the performance of stabilization (see EPA's BDAT Background Document for F006). EPA believes that the waste F012 is similar to F006 from the standpoint of BDAT metal treatability, both in terms of waste composition and in terms of the processes generating the wastes. These wastes are also similar to the nonwastewater treatment residuals from treatment of F011 wastes by chemical precipitation followed by filtration. Specifically, the types and concentrations of metals and inorganics in F006 and F012 wastes and the wastewater residuals from treatment of F011 wastes are similar. Also, substances such as oil and grease or sulfates that interfere with stabilization are not expected to be present in significant concentrations in these wastes. It follows, therefore, that performance data from stabilization treatment of F006 can reasonably be transferred to F012 nonwastewaters.

5.3 F010 Wastes

The data available to the Agency on incineration of F010 waste (presented in Table 4-6) indicate that incineration achieves a substantial reduction in cyanide concentration in the incinerator ash compared to the concentration in the untreated waste. Accuracy adjustment of these data is detailed in Table 5-7. No data were submitted on BDAT metals in the untreated waste or the ash residual. The Agency has no information as to which, if any, metals are present in F010 waste or the ash residual from incineration of this waste.

No data are available on the composition of the scrubber water from incineration of F010, but the Agency expects this scrubber water to be less difficult to treat than the other wastewaters regulated (F007 and F009 wastewaters) because the concentrations of cyanide and BDAT list metals would be lower. Therefore, the best demonstrated technology for these scrubber waters is alkaline chlorination followed by precipitation and filtration. No commenters submitted waste characterization data for F010 wastewaters or indicated that this waste would be more difficult to treat than other metal finishing wastes. EPA expects, however, that scrubber waters from incineration of cyanide wastes would meet the treatment standards promulgated for F007-F009, F011, and F012 wastewaters if generated from a well-designed and well-operated incineration treatment system because cyanide has been shown to be incinerable to nondetectable concentrations.

Incineration and alkaline chlorination are both commercially available technologies and thus are "available" for the purposes of establishing BDAT. Therefore, BDAT for F010 wastes is incineration followed by alkaline chlorination of the scrubber waters.

5.4 Wastes from Aluminum Conversion Coating: F019

Treatment standards for the wastewater and nonwastewater forms of F019 have not been promulgated with the Land Disposal Restrictions for the Second Third Scheduled Wastes. This waste was originally scheduled for regulation in the First Third, with the statutory deadline of August 8, 1988. Since the Agency did not promulgate standards for the wastewater and nonwastewater forms of F019, land disposal of these wastewaters and nonwastewaters will continue to be regulated by the "soft hammer" provisions in 40 CFR 268.8. EPA intends to promulgate numerical treatment standards for cyanides and metals constituents for F019 by May 8, 1990.

The Agency believes that F019 wastes are in a different treatability group because of the high concentration of iron complex cyanides in both the wastewaters and nonwastewaters. The Agency is investigating ultraviolet-light enhanced (UV) ozonation, wet air oxidation, and incineration as potential candidates for BDAT. Recovery or reuse of the iron cyanides is also being considered. The Agency believes that the source of the iron complex cyanides is the soluble ferrocyanide compounds (such as potassium ferrocyanide) that are used as constituents in aluminum conversion coating compounds or baths. Therefore, the only cyanides present in these conversion coating baths would be the iron complex cyanides that are used as a component of the coating. The Agency believes that F019 nonwastewaters or the wastewater treated to generate this waste have substantial concentrations of iron complex cyanides and cannot be treated by conventional oxidation-reduction processes. The Agency believes that the source of iron for the F019 waste is a legitimate source of iron and also believes that the F019 is a different subgroup within the metal finishing industry treatability group. Therefore, the Agency will continue to "soft hammer" the wastewater and nonwastewater forms of this waste.

Table 5-1 Summary of Accuracy Adjustment of Treatment Data for Total Cyanide in Electroplating Wastewaters

	Untreated waste concentration (mg/l)	Measured treated waste concentration (mg/l)	Percent recovery for matrix spike test	Accuracy-correction factor	Accuracy-adjusted concentration (mg/l)
Wet Air Oxidation					
Sample Set No. 2	CBI	<0.25	52	1.923	<0.48
Sample Set No. 3	CBI	3.22	52	1.923	6.19
Sample Set No. 4	CBI	<0.25	52	1.923	<0.48
Sample Set No. 5	CBI	<0.25	52	1.923	<0.48
Sample Set No. 6	CBI	<0.25	52	1.923	<0.48
Alkaline Chlorination					
Sample Set No. 1	71,759	0.95	94	1.06	1.01
Sample Set No. 2	12,000	0.95	94	1.06	1.01
Sample Set No. 3	17,206	<0.014	94	1.06	<0.015
Sample Set No. 4	25,936	<0.014	94	1.06	<0.015
Sample Set No. 5	16,914	<0.014	94	1.06	<0.015
Sample Set No. 6	59,421	0.028	94	1.06	0.030
Sample Set No. 7	31,994	0.028	94	1.06	0.030
Sample Set No. 8	41,900	<0.014	94	1.06	<0.015
Sample Set No. 9	18,882	<0.014	94	1.06	<0.015
Sample Set No. 10	1,270	0.17	94	1.06	0.18
Sample Set No. 12	12,085	<0.014	94	1.06	<0.015
Sample Set No. 13	10,902	0.070	94	1.06	0.074
Sample Set No. 14	16,010	0.070	94	1.06	0.074

Table 5-2 Summary of Accuracy Adjustment of Treatment Data for Amenable Cyanide in Electroplating Wastewaters

	Untreated waste concentration (mg/l)	Measured treated waste concentration (mg/l)	Percent recovery for matrix spike test	Accuracy-correction factor	Accuracy-adjusted concentration (mg/l)
Wet Air Oxidation					
Sample Set No. 2	CBI	<0.25	52	1.923	<0.48
Sample Set No. 3	CBI	<0.25	52	1.923	<0.48
Sample Set No. 4	CBI	<0.25	52	1.923	<0.48
Sample Set No. 5	CBI	<0.25	52	1.923	<0.48
Sample Set No. 6	CBI	<0.25	52	1.923	<0.48

Table 5-3 Summary of Accuracy Adjustment of Cyanide Data in F006 Waste as Generated

	Untreated waste concentration (mg/l)	Percent recovery for matrix spike test	Accuracy-correction factor	Accuracy-adjusted concentration (mg/l)
Alkaline Chlorination				
Sample Set No. 1	357	91.6	1.092	390
Sample Set No. 2	153	91.6	1.092	167
Sample Set No. 3	351	91.6	1.092	384
Sample Set No. 4	374	91.6	1.092	408
Sample Set No. 5	235	91.6	1.092	256
Sample Set No. 6	245	91.6	1.092	267
Sample Set No. 7	169	91.6	1.092	185
Sample Set No. 8	189	91.6	1.092	207
Sample Set No. 9	106.3	91.6	1.092	116
Sample Set No. 10	143	91.6	1.092	156
Sample Set No. 11	114.1	91.6	1.092	125
Sample Set No. 12	252.4	91.6	1.092	276
Sample Set No. 13	203.1	91.6	1.092	222

Table 5-4 Summary of Accuracy Adjustment of Treatment Data for Total Cyanide in Electroplating and Metal Heat Treating Wastewaters

	Untreated waste concentration (mg/l)	Measured treated waste concentration (mg/l)	Percent recovery for matrix spike test	Accuracy-correction factor	Accuracy-adjusted concentration (mg/l)
Alkaline Chlorination					
Sample Set No. 1	71,759	0.95	94	1.06	1.01
Sample Set No. 2	12,000	0.95	94	1.06	1.01
Sample Set No. 3	17,206	<0.014	94	1.06	<0.015
Sample Set No. 4	25,936	<0.014	94	1.06	<0.015
Sample Set No. 5	16,914	<0.014	94	1.06	<0.015
Sample Set No. 6	59,421	0.028	94	1.06	<0.015
Sample Set No. 7	31,994	0.028	94	1.06	0.030
Sample Set No. 8	41,900	<0.014	94	1.06	0.030
Sample Set No. 9	18,882	<0.014	94	1.06	<0.015
Sample Set No. 10	1,270	0.17	94	1.06	<0.015
Sample Set No. 12	12,085	<0.014	94	1.06	0.18
Sample Set No. 13	10,902	0.070	94	1.06	<0.015
Sample Set No. 14	16,010	0.070	94	1.06	0.074
					0.074
Electrolytic Oxidation/Alkaline Chlorination					
Sample Set No. 1	5,350	103	88	1.136	117
Sample Set No. 2	62.6	<0.01	88	1.136	<0.011

Table 5-5 Summary of Accuracy Adjustment of Treatment Data for Amenable Cyanide in Electroplating and Metal Heat Treating Wastewaters

	Untreated waste concentration (mg/l)	Measured treated waste concentration (mg/l)	Percent recovery for matrix spike test	Accuracy-correction factor	Accuracy-adjusted concentration (mg/l)
Electrolytic Oxidation/Alkaline Chlorination					
Sample Set No. 1					
Cyanide (amenable)	-	-	-	-	3.0
Cyanide (chlorinated)	I	114	100	1.0	114
Cyanide (total)	5350	103	88	1.136	117
Sample Set No. 2					
Cyanide (amenable)	29.2	-	-	-	<0.017
Cyanide (chlorinated)	33.4	<0.01	60	1.67	<0.017
Cyanide (total)	62.6	<0.01	88	1.136	<0.011

- = Not available. Quantities actually measured were total cyanide and "chlorinated cyanide," which were both adjusted for accuracy. The accuracy-adjusted value for chlorinated cyanide was then subtracted from the accuracy-adjusted value for total cyanide to obtain the accuracy-adjusted concentration of amenable cyanide. (See Appendix A for analytical recoveries and Appendix D for detailed calculations.)

I = Analytical interference. Value for total cyanide concentration was 5350.

Table 5-6 Summary of Accuracy Adjustment of Cyanide Data in F012 Waste as Generated

	Untreated waste concentration (mg/l)	Percent recovery for matrix spike test	Accuracy-correction factor	Accuracy-adjusted concentration (mg/l)
Electrolytic Oxidation/Alkaline Chlorination				
Sample Set No. 1				
Cyanide (amenable)	-	-	-	<2.3
Cyanide (chlorinated)	-	-	-	-
Cyanide (total)	99.4	102	0.98	97.4
Sample Set No. 2				
Cyanide (amenable)	-	-	-	7.9
Cyanide (chlorinated)	-	-	-	-
Cyanide (total)	34.7	93	1.08	37.3
Alkaline Chlorination				
Sample Set No. 1	357	91.6	1.092	390
Sample Set No. 2	153	91.6	1.092	167
Sample Set No. 3	351	91.6	1.092	384
Sample Set No. 4	374	91.6	1.092	408
Sample Set No. 5	235	91.6	1.092	256
Sample Set No. 6	245	91.6	1.092	267
Sample Set No. 7	169	91.6	1.092	185
Sample Set No. 8	189	91.6	1.092	207
Sample Set No. 9	106.3	91.6	1.092	116
Sample Set No. 10	143	91.6	1.092	156
Sample Set No. 11	114.1	91.6	1.092	125
Sample Set No. 12	252.4	91.6	1.092	276
Sample Set No. 13	203.1	91.6	1.092	222

- = Not available. Quantities actually measured were total cyanide and "chlorinated cyanide," which were both adjusted for accuracy. The accuracy-adjusted value for chlorinated cyanide was then subtracted from the accuracy-adjusted value for total cyanide to obtain the accuracy-adjusted concentration of amenable cyanide. (See Appendix A for QA/QC and Appendix D for detailed calculations.)

Table 5-7 Summary of Accuracy Adjustment of Treatment Data for Total Cyanide in F010 Waste

	Untreated waste concentration (mg/kg)	Measured treated waste concentration (mg/kg)	Percent recovery for matrix spike test	Accuracy-correction factor	Accuracy-adjusted concentration (mg/kg)
Sample Set No. 1					
Cyanide (total)	21,000[a]	0.45	96	1.04	0.468
Sample Set No. 2					
Cyanide (total)	21,000[a]	0.40	96	1.04	0.416
Sample Set No. 3					
Cyanide (total)	21,000[a]	0.88	96	1.04	0.915

[a] Average of two untreated waste samples.

6. SELECTION OF REGULATED CONSTITUENTS

This section presents the rationale for selection of the promulgated regulated constituents for the treatment of F006-F012 wastes.

Constituents selected for regulation must satisfy the following criteria:

1. They must be on the BDAT list of regulated constituents or must be indicators for other BDAT list constituents. (Presence on the BDAT list implies the existence of approved techniques for analyzing the constituent in treated wastes.)
2. They must be present in, or suspected of being present in, the untreated waste. For example, in some cases, analytical difficulties (such as masking) may prevent a constituent from being identified in the untreated waste, but its identification in a treatment residual may lead the Agency to conclude that it is present in the untreated waste.
3. Where performance data are transferred, the selected constituents must be easier to treat than the waste constituent(s) from which performance data are transferred. Factors for assessing ease of treatment will vary according to the technology of concern. For instance, for incineration the factors include bond dissociation energy, thermal conductivity, and boiling point.

From the group of constituents that are eligible to be regulated, EPA may select a subset of constituents as representative of the broader group. For instance, out of a group of constituents that react similarly to treatment, the Agency might name only those found in the highest concentrations or those that are the most difficult to treat as regulated constituents for the purpose of setting a standard.

6.1 Identification of BDAT List Constituents

Table 6-1 shows which BDAT list constituents were analyzed for in all wastes tested by EPA and submitted by industry (F007, F011, F012), which constituents were detected, and which constituents the Agency believes may be present even though they were not detected in the untreated waste on which treatment tests were performed. BDAT list metals and cyanide were detected in all of the wastes sampled.

For the F007 waste tested, one volatile organic compound, methanol, was detected. One PCB compound, Aroclor 1254, was detected at a concentration slightly above the detection limit, and several volatile and semivolatile organic compounds were detected in the F012 waste tested. No other BDAT list organic compounds were detected, or are believed to be commonly present, in any of the wastes tested or any of the wastes regulated by this document based on the Agency's knowledge of the electroplating and heat treating processes. The detection of a PCB compound in the F012 waste tested is probably attributable to a cleanup of PCB transformers that had recently occurred at the plant where this waste was collected.

The methanol detected in the F007 waste tested was probably a constituent of the electroplating bath; since methanol is not commonly used in such an application, it is not proposed for regulation. The organic compounds detected in F012 (bis(2-ethylhexyl) phthalate, acetone, chloroform, methylene chloride, and toluene) were probably contaminants of the rinsewaters treated along with the quenching wastewaters. These organic compounds were all found at very low concentrations and are not believed to be treatable at these concentrations.

6.2 Determination of Regulated Constituents

For the F007, F008, and F009 wastes, EPA is promulgating treatment standards for total and amenable cyanide in both wastewater and nonwastewater treatment residuals based on the performance of alkaline chlorination. The Agency is also promulgating treatment standards for chromium, lead, and nickel in wastewaters based on the performance of chemical precipitation followed by filtration, and cadmium, chromium, lead, nickel, and silver in F007, F008, and F009 nonwastewaters based on the performance of stabilization. For F006, EPA is promulgating nonwastewater treatment standards for amenable and total cyanide based on alkaline chlorination.

Standards for amenable and total cyanides are promulgated based on the total waste composition analysis. EPA feels that because these standards are based on a destruction technology, the appropriate measure of performance is total waste composition. Also, because there may be a difference in the performance of cyanide destruction technologies between complexed and noncomplexed cyanide, both amenable and total cyanide standards are promulgated.

All of the metals listed above are commonly found in electroplating and heat treating wastes, based on the waste characterization data presented in Appendix B. The Agency has no data on the treatment of wastewaters for cadmium and silver by chemical precipitation, but believes that these constituents will be controlled by treatment of the other metals for which treatment standards are promulgated. The Agency may propose numerical standards for these constituents at a later date if more treatment data become available.

The only other metals that are commonly detected in these wastes at high concentrations, according to the waste characterization data presented in Section 2, are copper and zinc. EPA is not regulating copper and zinc for the wastes in this subcategory because these constituents are not listed in Appendix VIII of 40 CFR Part 261 as elemental constituents but rather as specific compounds (i.e., copper cyanide, zinc phosphide, and zinc cyanide). In any case, treatment of the other BDAT list metals by chemical precipitation and/or stabilization will also reduce leachate concentrations of both of these metals in wastewater and nonwastewater treatment residuals.

The Agency is promulgating standards for both amenable and total cyanide for F011 and F012 wastewaters and nonwastewaters. Regulated constituent selection for wastewaters is based on alkaline chlorination. Regulated constituent selection for nonwastewaters is based on electrolytic oxidation followed by alkaline chlorination. Treatment standards for amenable and total cyanides are based on the total waste composition analysis. EPA feels that because these standards are based on a destruction technology, the appropriate measure of performance is total waste composition. Also, because there may be a difference in the performance of cyanide destruction technologies between complexed and noncomplexed cyanide, both amenable and total cyanide standards are promulgated.

For metals in F011 and F012 wastewaters, the Agency is promulgating treatment standards for chromium, lead, and nickel. For F011 and F012 nonwastewaters, the Agency is promulgating treatment standards for cadmium, chromium, lead, nickel, and silver. Regulated constituent selection for wastewaters is based on treatment of the effluent from alkaline chlorination by chemical precipitation followed by filtration for the wastewaters. Regulated constituent selection for nonwastewaters is based on stabilization of the nonwastewater residual. All of the metals listed above are commonly found in electroplating and heat treating wastes based on the waste characterization data presented in Appendix B. The Agency has no data on the treatment of wastewaters for cadmium and silver by chemical precipitation, but believes that these constituents will be controlled by treatment of the other metals regulated. The Agency may propose numerical standards for these constituents at a later date if more treatment data become available.

For F010, EPA is promulgating treatment standards for total cyanide in the total composition analysis for both wastewater and nonwastewater residuals and amenable cyanide for wastewaters. For incineration, the Agency believes that total cyanide is the appropriate measure of performance, as it has no evidence that complexed cyanides are any more difficult to treat by thermal treatment methods such as incineration than are free cyanides. As discussed in Section 5.3, EPA has no data on metals in this waste and therefore is not promulgating treatment standards for metals. The Agency is not precluded from regulating these metals in the future if more treatment data become available.

Table 6-1 Status of BDAT List Constituent Presence in Untreated Tested Wastes

BDAT reference no.	Constituent	F007	F011	F012
	Volatile Organics			
222.	Acetone	ND	ND	D
1.	Acetonitrile	ND	ND	ND
2.	Acrolein	ND	ND	ND
3.	Acrylonitrile	ND	ND	ND
4.	Benzene	ND	ND	ND
5.	Bromodichloromethane	ND	ND	ND
6.	Bromomethane	ND	ND	ND
223.	n-Butyl alcohol	ND	NA	NA
7.	Carbon tetrachloride	ND	ND	ND
8.	Carbon disulfide	ND	ND	ND
9.	Chlorobenzene	ND	ND	ND
10.	2-Chloro-1,3-butadiene	ND	ND	ND
11.	Chlorodibromomethane	ND	ND	ND
12.	Chloroethane	ND	ND	ND
13.	2-Chloroethyl vinyl ether	ND	ND	ND
14.	Chloroform	ND	ND	ND
15.	Chloromethane	ND	ND	D
16.	3-Chloropropene	ND	ND	ND
17.	1,2-Dibromo-3-chloropropane	ND	ND	ND
18.	1,2-Dibromoethane	ND	ND	ND
19.	Dibromomethane	ND	ND	ND
20.	trans-1,4-Dichloro-2-butene	ND	ND	ND
21.	Dichlorodifluoromethane	ND	ND	ND
22.	1,1 Dichloroethane	ND	ND	ND
23.	1,2-Dichloroethane	ND	ND	ND
24.	1,1-Dichloroethylene	ND	ND	ND
25.	trans-1,2-Dichloroethene	ND	ND	ND
26.	1,2-Dichloropropane	ND	ND	ND
27.	trans-1,3-Dichloropropene	ND	ND	ND
28.	cis-1,3-Dichloropropene	ND	ND	ND
29.	1,4-Dioxane	ND	ND	ND
224.	2-Ethoxyethanol	ND	NA	NA
225.	Ethyl acetate	ND	NA	NA
226.	Ethyl benzene	ND	ND	ND
30.	Ethyl cyanide	ND	ND	ND
227.	Ethyl ether	ND	ND	ND
31.	Ethyl methacrylate	ND	NA	NA
214.	Ethylene oxide	ND	ND	ND
32.	Iodomethane	ND	ND	ND
33.	Isobutyl alcohol	ND	ND	ND
228.	Methanol	D	NA	NA
34.	Methyl ethyl ketone	ND	ND	ND

Table 6-1 (continued)

BDAT reference no.	Constituent	F007	F011	F012
	Volatile Organics (continued)			
229.	Methyl isobutyl ketone	ND	ND	ND
35.	Methyl methacrylate	ND	ND	ND
37.	Methacrylonitrile	ND	ND	ND
38.	Methylene chloride	ND	ND	D
230.	2-Nitropropane	ND	NA	NA
39.	Pyridine	ND	ND	ND
40.	1,1,1,2-Tetrachloroethane	ND	ND	ND
41.	1,1,2,2-Tetrachloroethane	ND	ND	ND
42.	Tetrachloroethene	ND	ND	ND
43.	Toluene	ND	ND	D
44.	Tribromomethane	ND	ND	ND
45.	1,1,1-Trichloroethane	ND	ND	ND
46.	1,1,2-Trichloroethane	ND	ND	ND
47.	Trichloroethene	ND	ND	ND
48.	Trichloromonofluoromethane	ND	ND	ND
49.	1,2,3-Trichloropropane	ND	ND	ND
231.	1,1,2-Trichloro-1,2,2-trifluoroethane	NA	NA	NA
50.	Vinyl chloride	ND	ND	ND
215.	1,2-Xylene	ND	ND	ND
216.	1,3-Xylene	ND	ND	ND
217.	1,4-Xylene	ND	ND	ND
	Semivolatile Organics			
51.	Acenaphthylene	ND	ND	ND
52.	Acenaphthene	ND	ND	ND
53.	Acetophenone	ND	ND	ND
54.	2-Acetylaminofluorene	ND	ND	ND
55.	4-Aminobiphenyl	ND	ND	ND
56.	Aniline	ND	ND	ND
57.	Anthracene	ND	ND	ND
58.	Aramite	NA	ND	ND
59.	Benz(a)anthracene	ND	ND	ND
218.	Benzal chloride	ND	NA	NA
60.	Benzenethiol	NA	ND	ND
61.	Deleted			
62.	Benzo(a)pyrene	ND	ND	ND
63.	Benzo(b)fluoranthene	ND	ND	ND
64.	Benzo(ghi)perylene	ND	ND	ND
65.	Benzo(k)fluoranhene	ND	ND	ND
66.	p-Benzoquinone	NA	ND	ND

Table 6-1 (continued)

BDAT reference no.	Constituent	F007	F011	F012
	Semivolatile Organics (continued)			
67.	Bis(2-chloroethoxy)methane	ND	ND	ND
68.	Bis(2-chloroethyl) ether	ND	ND	ND
69.	Bis(2-chloroisopropyl) ether	ND	ND	ND
70.	Bis(2-ethylhexyl) phthalate	ND	ND	D
71.	4-Bromophenyl phenyl ether	ND	ND	ND
72.	Butylbenzyl phthalate	ND	ND	ND
73.	2-sec-Butyl-4,6-dinitrophenol	ND	ND	ND
74.	p-Chloroaniline	ND	ND	ND
75.	Chlorobenzilate	ND	ND	ND
76.	p-Chloro-m-cresol	ND	ND	ND
77.	2-Chloronaphthalene	ND	ND	ND
78.	2-Chlorophenol	ND	ND	ND
79.	3-Chloropropionitrile	ND	ND	ND
80.	Chrysene	ND	ND	ND
81.	ortho-Cresol	ND	ND	ND
82.	para-Cresol	ND	ND	ND
232.	Cyclohexanone	ND	NA	NA
83.	Dibenz(a,h)anthracene	ND	ND	ND
84.	Dibenzo(a,e)pyrene	NA	ND	ND
85.	Dibenzo(a,i)pyrene	NA	ND	ND
86.	m-Dichlorobenzene	ND	ND	ND
87.	o-Dichlorobenzene	ND	ND	ND
88.	p-Dichlorobenzene	ND	ND	ND
89.	3,3'-Dichlorobenzidine	ND	ND	ND
90.	2,4-Dichlorophenol	ND	ND	ND
91.	2,6-Dichlorophenol	ND	ND	ND
92.	Diethyl phthalate	ND	ND	ND
93.	3,3'-Dimethoxybenzidine	ND	ND	ND
94.	p-Dimethylaminoazobenzene	ND	ND	ND
95.	3,3'-Dimethylbenzidine	ND	ND	ND
96.	2,4-Dimethylphenol	ND	ND	ND
97.	Dimethyl phthalate	ND	ND	ND
98.	Di-n-butyl phthalate	ND	ND	ND
99.	1,4-Dinitrobenzene	ND	ND	ND
100.	4,6-Dinitro-o-cresol	ND	ND	ND
101.	2,4-Dinitrophenol	ND	ND	ND
102.	2,4-Dinitrotoluene	ND	ND	ND
103.	2,6-Dinitrotoluene	ND	ND	ND
104.	Di-n-octyl phthalate	ND	ND	ND
105.	Di-n-propylnitrosamine	ND	ND	ND
106.	Diphenylamine	ND	ND	ND
219.	Diphenylnitrosamine	ND	ND	ND

Table 6-1 (continued)

BDAT reference no.	Constituent	F007	F011	F012
	Semivolatile Organics (continued)			
107.	1,2-Diphenylhydrazine	ND	ND	ND
108.	Fluoranthene	ND	ND	ND
109.	Fluorene	ND	ND	ND
110.	Hexachlorobenzene	ND	ND	ND
111.	Hexachlorobutadiene	ND	ND	ND
112.	Hexachlorocyclopentadiene	ND	ND	ND
113.	Hexachloroethane	ND	ND	ND
114.	Hexachlorophene	NA	ND	ND
115.	Hexachloropropene	ND	ND	ND
116.	Indeno(1,2,3-cd)pyrene	ND	ND	ND
117.	Isosafrole	ND	ND	ND
118.	Methapyrilene	ND	ND	ND
119.	3-Methylcholanthrene	NA	ND	ND
120.	4,4'-Methylenebis-(2-chloroaniline)	ND	ND	ND
36.	Methyl methanesulfonate	ND	ND	ND
121.	Naphthalene	ND	ND	ND
122.	1,4-Naphthoquinone	ND	ND	ND
123.	1-Naphthylamine	NA	ND	ND
124.	2-Naphthylamine	ND	ND	ND
125.	p-Nitroaniline	ND	ND	ND
126.	Nitrobenzene	ND	ND	ND
127.	4-Nitrophenol	ND	ND	ND
128.	N-Nitrosodi-n-butylamine	ND	ND	ND
129.	N-Nitrosodiethylamine	ND	ND	ND
130.	N-Nitrosodimethylamine	ND	ND	ND
131.	N-Nitrosomethylethylamine	ND	ND	ND
132.	N-Nitrosomorpholine	ND	ND	ND
133.	N-Nitrosopiperidine	ND	ND	ND
134.	N-Nitrosopyrrolidine	ND	ND	ND
135.	5-Nitro-o-toluidine	ND	ND	ND
136.	Pentachlorobenzene	ND	ND	ND
137.	Pentachloroethane	NA	ND	ND
138.	Pentachloronitrobenzene	ND	ND	ND
139.	Pentachlorophenol	ND	ND	ND
140.	Phenacetin	ND	ND	ND
141.	Phenanthrene	ND	ND	ND
142.	Phenol	ND	ND	ND
220.	Phthalic anhydride	ND	NA	NA
143.	2-Picoline	ND	ND	ND
144.	Pronamide	ND	ND	ND
145.	Pyrene	ND	ND	ND
146.	Resorcinol	NA	ND	ND

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Table 6-1 (continued)

BDAT reference no.	Constituent	F007	F011	F012
	Semivolatile Organics (continued)			
147.	Safrole	ND	ND	ND
148.	1,2,4,5-Tetrachlorobenzene	ND	ND	ND
149.	2,3,4,6-Tetrachlorophenol	ND	ND	ND
150.	1,2,4-Trichlorobenzene	ND	ND	ND
151.	2,4,5-Trichlorophenol	ND	ND	ND
152.	2,4,6-Trichlorophenol	ND	ND	ND
153.	Tris(2,3-dibromopropyl) phosphate	ND	ND	ND
	Metals			
154.	Antimony	ND	D	ND
155.	Arsenic	ND	ND	ND
156.	Barium	ND	D	D
157.	Beryllium	ND	ND	ND
158.	Cadmium	ND-X	D	D
159.	Chromium (total)	D	D	D
221.	Chromium (hexavalent)	I-Y	ND	I
160.	Copper	D	D	D
161.	Lead	ND	D	D
162.	Mercury	D	ND	ND
163.	Nickel	ND-X	D	D
164.	Selenium	ND	ND	ND
165.	Silver	ND-X	D	D
166.	Thallium	ND	ND	ND
167.	Vanadium	ND	D	D
168.	Zinc	D	D	D
	Inorganics Other Than Metals			
169.	Cyanide	D	D	D
170.	Fluoride	D	D	D
171.	Sulfide	NA	ND	ND
	Organochlorine Pesticides			
172.	Aldrin	ND	NA	NA
173.	alpha-BHC	ND	NA	NA
174.	beta-BHC	ND	NA	NA
175.	delta-BHC	ND	NA	NA

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Table 6-1 (continued)

BOAT reference no.	Constituent	F007	F011	F012
	Organochlorine Pesticides (continued)			
176.	gamma-BHC	ND	NA	NA
177.	Chlordane	ND	NA	NA
178.	DDD	ND	NA	NA
179.	DDE	ND	NA	NA
180.	DDT	ND	NA	NA
181.	Dieldrin	ND	NA	NA
182.	Endosulfan I	ND	NA	NA
183.	Endosulfan II	ND	NA	NA
184.	Endrin	ND	NA	NA
185.	Endrin aldehyde	ND	NA	NA
186.	Heptachlor	ND	NA	NA
187.	Heptachlor epoxide	ND	NA	NA
188.	Isodrin	ND	NA	NA
189.	Kepone	ND	NA	NA
190.	Methoxyclor	ND	NA	NA
191.	Toxaphene	ND	NA	NA
	Phenoxyacetic Acid Herbicides			
192.	2,4-Dichlorophenoxyacetic acid	ND	NA	NA
193.	Silvex	ND	NA	NA
194.	2,4,5-T	ND	NA	NA
	Organophosphorous Insecticides			
195.	Disulfoton	ND	NA	NA
196.	Famphur	ND	NA	NA
197.	Methyl parathion	ND	NA	NA
198.	Parathion	ND	NA	NA
199.	Phorate	ND	NA	NA
	PCBs			
200.	Aroclor 1016	ND	ND	ND
201.	Aroclor 1221	ND	ND	ND
202.	Aroclor 1232	ND	ND	ND
203.	Aroclor 1242	ND	ND	ND
204.	Aroclor 1248	ND	ND	ND
205.	Aroclor 1254	ND	ND	D
206.	Aroclor 1260	ND	ND	ND

Table 6-1 (continued)

BDAT reference no.	Constituent	F007	F011	F012
	Dioxins and Furans			
207.	Hexachlorodibenzo-p-dioxins	ND	ND	ND
208.	Hexachlorodibenzofurans	ND	ND	ND
209.	Pentachlorodibenzo-p-dioxins	ND	ND	ND
210.	Pentachlorodibenzofurans	ND	ND	ND
211.	Tetrachlorodibenzo-p-dioxins	ND	ND	ND
212.	Tetrachlorodibenzofurans	ND	ND	ND
213.	2,3,7,8-Tetrachlorodibenzo-p-dioxin	NA	ND	ND

D = Detected
ND = Not detected.
NA = Not analyzed.
I = Analytical interference (matrix effects) prevented analysis.
X = Believed to be present based on engineering analysis of waste-generating process.
Y = Believed to be present based on detection in treated residuals.

References: USEPA 1988e, 1988f.

METHOD OF MEASUREMENTS FOR THERMAL CONDUCTIVITY

The comparative method of measuring thermal conductivity has been proposed as an ASTM test method under the name "Guarded, Comparative, Longitudinal Heat Flow Technique." A thermal heat flow circuit is used which is the analog of an electrical circuit with resistances in series. A reference material is chosen to have a thermal conductivity close to that estimated for the sample. Reference standards (also known as heat meters) having the same cross-sectional dimensions as the sample are placed above and below the sample. An upper heater, a lower heater, and a heat sink are added to the "stack" to complete the heat flow circuit. See Figure 1.

The temperature gradients (analogous to potential differences) along the stack are measured with type K (chromel/alumel) thermocouples placed at known separations. The thermocouples are placed into holes or grooves in the references and also in the sample whenever the sample is thick enough to accommodate them.

For molten samples, pastes, greases, and other materials that must be contained, the material is placed into a cell consisting of a top and bottom of Pyrex 7740 and a containment ring of marinite. The sample is 2 inches in diameter and 0.5 inch thick. Thermocouples are not placed into the sample, rather, the temperatures measured in the Pyrex are extrapolated to give the temperature at the top and bottom surfaces of the sample material. The Pyrex disks also serve as the thermal conductivity reference material.

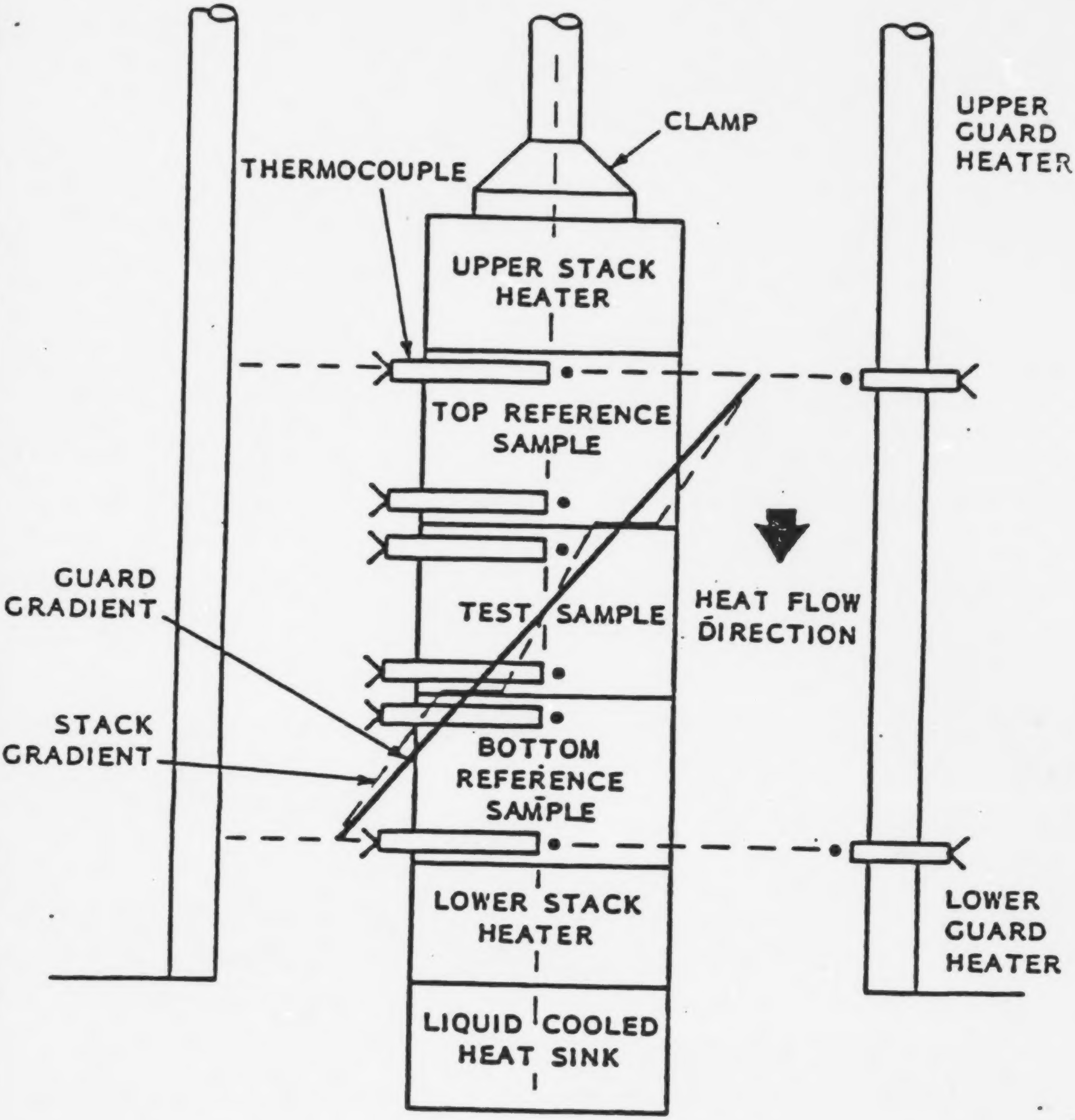
UPPER GUARD HEATER
CLAMP
THERMOCOUPLE
UPPER STACK HEATER
TOP REFERENCE SAMPLE
HEAT FLOW DIRECTION
GUARD GRADIENT
TEST SAMPLE
STACK GRADIENT
BOTTOM REFERENCE SAMPLE
LOWER STACK HEATER
LOWER GUARD HEATER
LIQUID COOLED HEAT SINK

Figure 1.

SCHEMATIC DIAGRAM OF THE COMPARATIVE METHOD

Reference: VSR-1 C-3 January 1988

The stack is clamped with a reproducible load to ensure intimate contact between the components. To produce a linear flow of heat down the stack and reduce the amount of heat that flows radially, a guard tube is placed around the stack and the intervening space is filled with insulating grains or powder. The temperature gradient in the guard is matched to that in the stack to further reduce radial heat flow.

The comparative method is a steady-state method of measuring thermal conductivity. When equilibrium is reached, the heat flux (analogous to current flow) down the stack can be determined from the references. The heat into the sample is given by

$$Qn_{in} = \lambda_{top}(dT/dx)_{top}$$

and the heat out of the sample is given by

$$Q_{out} = \lambda_{bottom}(dT/dx)_{bottom}$$

where

λ = thermal conductivity

dT/dx = temperature gradient

and top refers to the upper reference while bottom refers to the lower reference. If the heat was confined to flow just down the stack, then Q_{in} and Q_{out} would be equal. If Q_{in} and Q_{out} are in reasonable agreement, the average heat flow is calculated from

$$Q = (Q_{in} + Q_{out})/2.$$

The sample thermal conductivity is then found from

$$\lambda_{sample} = Q/(dT/dx)_{sample}$$

The result for the K102 Activated Charcoal Waste tested here is given in Table 1. The sample was held at an average temperature of 42°C with a 53°C temperature drop across the sample for approximately 20 hours before the temperature profile became steady and the conductivity measured. At the conclusion of the test, it appeared that some "drying" of the sample had occurred.

Table 1 The Results of the Measurement of the Thermal Conductivity Using the Comparative Method

Sample	Temperature	Thermal conductivity
	(°C)	(W/mK)*
K101 waste	39	.273
K102 activated charcoal waste	42	.136

*1 W/mK = 6.933 Btu in/h ft^2 °F = .5778 Btu/h ft °F.

7. CALCULATION OF PROMULGATED BDAT TREATMENT STANDARDS

This section presents the calculation of the promulgated treatment standards for F006 through F012 wastes using analytical treatment data for the regulated constituents selected in Section 6. The Agency bases treatment standards for regulated constituents on the performance of well-designed and well-operated BDAT treatment systems. These standards must account for analytical limitations in available performance data and must be adjusted for variabilities related to treatment, sampling, and analytical techniques and procedures.

BDAT standards are determined for each constituent by multiplying the arithmetic mean of accuracy-adjusted constituent concentrations detected in treated waste by a "variability factor" specific to each constituent for each treatment technology defined as BDAT. Accuracy adjustment of performance data has been discussed in Section 5 in relation to defining "substantial treatment." Variability factors correct for normal variations in the performance of a particular technology over time. They are designed to reflect the 99th percentile level of performance that the technology achieves in commercial operation. (For more information on the principles of calculating variability factors, see EPA's publication Methodology for Developing BDAT Treatment Standards (USEPA 1988d).) Details on the calculation of variability factors for F006 through F012 wastes are presented in this section.

Where EPA has identified BDAT for a particular waste, but because of data limitations or for some other compelling reason cannot define specific treatment standards for that waste, the Agency can require the use of that treatment process as a technology standard. Similarly, where there are no known generators of a waste, or where EPA believes that the waste can be totally recycled or reused as a raw material, the Agency may specify a "no land disposal as generated" standard, which effectively amounts to setting the performance standard at zero for all waste constituents.

7.1 Cyanide

EPA is promulgating both nonwastewater and wastewater treatment standards for amenable and total cyanide for F007, F008, F009, F010, F011, and F012. Promulgated cyanide standards for wastewaters for all of the wastes listed above are based on performance data from alkaline chlorination. The performance data on alkaline chlorination were received by the Agency during the comment period and are part of the Administrative Record for this rule. These data were collected from treatment of a mixture of wastes including F006, F007, F008, F009, F011, F012, P030, P106, and other cyanide-containing wastes generated by the metal finishing industry. Promulgated nonwastewater cyanide treatment standards for F006, F007, F008, and F009 are based on analysis of F006 waste generated as a residual from treatment of F006, F007, F008, F009, and other metal finishing wastes by alkaline chlorination followed by chemical precipitation and sludge dewatering. The Agency has taken into account the precision of the analytical methods for cyanide analysis in the calculation of the treatment standards for amenable cyanide from the alkaline chlorination data presented in Table 4-3.

The promulgated nonwastewater treatment standards for F011 and F012 are based on analysis of F012 waste generated as a residual from treatment of F011 waste and heat treating quenching wastewaters by electrolytic oxidation followed by alkaline chlorination, chemical precipitation, filtration, and sludge dewatering. Promulgated nonwastewater standards for F010 are based on data from treatment of this waste and a similar waste by incineration.

7.2 BDAT List Metals

EPA is promulgated nonwastewater treatment standards for BDAT list metals for F007-F009, F011, and F012 based on the treatment standards established for treatment of F006 by stabilization. (See EPA's Best Demonstrated Available Technology (BDAT) Background Document for F006 (USEPA 1988a).) Wastewater treatment standards for these wastes are also being promulgated by the Agency based on transfer of the treatment standards established for treatment of K062 waste by chemical precipitation followed by filtration. (See EPA's Best Demonstrated Availability Technology (BDAT) Background Document for K062 (USEPA 1988b).)

Table 7-1 Calculation of Wastewater Treatment Standards for Total Cyanide for Waste Codes F007, F008, F009, F010, F011, and F012 Based on Alkaline Chlorination

Regulated constituent (units)	Accuracy-adjusted treated waste concentration[a]	Mean treated waste concentration	Variability factor (VF)	Treatment standard (total composition)
Wastewater (mg/l):				
Cyanide (total)	1.01 1.01 0.015 0.015 0.015 0.030 0.030 0.015 0.015 0.18 0.015 0.074 0.074	0.192	9.8	1.9

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[a] See Tables 5-1 and 5-4.

Table 7-2 Calculation of Nonwastewater Treatment Standards for Total and Amenable Cyanide for F006, F007, F008, and F009 Wastes Based on Generation of F006 Waste by a Well-Operated Treatment Process Consisting of Alkaline Chlorination, Chemical Precipitation, Filtration, and Sludge Dewatering

Regulated constituent (units)	Accuracy-adjusted treated waste concentration[a]	Mean treated waste concentration	Variability factor (VF)	Treatment standard (total composition)
Nonwastewater (mg/kg):				
Cyanide (total)	390.11	242.9	2.4	590
	166.56			
	383.68			
	408.0			
	256.5			
	267.43			
	185.01			
	206.78			
	116.02			
	156.11			
	124.54			
	275.58			
	221.83			

[a] See Table 5-3.

Table 7-3 Calculation of Nonwastewater Treatment Standards for Total and Amenable Cyanide for F011 and F012 Wastes Based on Generation of F012 Waste by a Well-Operated Treatment Process Consisting of Electrolytic Oxidation, Alkaline Chlorination, Chemical Precipitation, Filtration, and Sludge Dewatering

Regulated constituent (units)	Accuracy-adjusted treated waste concentration[a]	Mean treated waste concentration	Variability factor (VF)	Treatment standard (total composition)
Nonwastewater (mg/kg):				
Cyanide (total)	97.4 37.3	67.35	1.58	110
Cyanide (amenable)	<2.3 7.9	5.1	1.79	9.1

[a] See Table 5-6.

Table 7-4 Calculation of Nonwastewater Treatment Standards for Incineration of F010

Regulated constituent (units)	Accuracy-adjusted treated waste concentration[a]	Mean treated waste concentration	Variability factor (VF)	Treatment standard (total composition)
Nonwastewater (mg/kg):				
Cyanide (total)	0.468 0.416 0.915	0.60	2.53	1.5

[a] See Table 5-7.

Table 7-5 BDAT Treatment Standards for F007, F008, and F009

Constituent	Wastewater	Nonwastewater	
	Total composition (mg/l)	Total composition (mg/kg)	TCLP (mg/l)
Cyanide (amenable)	0.10	30	NA
Cyanide (total)	1.9	590	NA
Cadmium	-	NA	0.066
Chromium	0.32	NA	5.2
Lead	0.04	NA	0.51
Nickel	0.44	NA	0.32
Silver	-	NA	0.072

NA = Not applicable.
- = No treatment standard.

Table 7-6 BDAT Treatment Standards for F006 (Cyanide)

Constituent	Nonwastewater	
	Total composition (mg/kg)	TCLP (mg/l)
Cyanide (amenable)	30	NA
Cyanide (total)	590	NA

NA = Not applicable.

Table 7-7 BDAT Treatment Standards for F011 and F012

Constituent	Wastewater	Nonwastewater	
	Total composition (mg/l)	Total composition (mg/kg)	TCLP (mg/l)
Cyanide (amenable)	0.10	9.1	NA
Cyanide (total)	1.9	110	NA
Cadmium	-	NA	0.066
Chromium	0.32	NA	5.2
Lead	0.04	NA	0.51
Nickel	0.44	NA	0.32
Silver	-	NA	0.072

NA = Not applicable.

- = No treatment standard.

Table 7-8 BDAT Treatment Standards for F010

Constituent	Wastewater	Nonwastewater	
	Total composition (mg/l)	Total composition (mg/kg)	TCLP (mg/l)
Cyanide (amenable)	0.10	-	NA
Cyanide (total)	1.9	1.5	NA

NA = Not applicable.
- = No treatment standard.

8. P WASTE CODES

This section addresses regulation of those P wastes that are similar to the metal finishing cyanide wastes. These wastes, listed in Table 8-1, are identified in 40 CFR 261.33 as "discarded commercial chemical products, off-specification species, container residues, and spill residues thereof."

8.1 Industries Affected

Industries that may generate these wastes are the manufacturers of cyanide compounds listed in Table 8-1 as well as electroplaters, heat treaters, and other industries that use inorganic cyanide salts. In addition, hydrogen cyanide is a chemical intermediate used in the production of acetone cyanohydrin, adiponitrile, cyanuric chloride, methyl methacrylate, methionine, sodium cyanide, and other chemicals. Thus, P063 wastes may be generated by producers of these chemicals.

8.2 Applicable and Demonstrated Treatment Technologies

The compounds listed in Table 8-1 are soluble in water to form waste solutions that are similar in nature to the F011 waste tested by the Agency and other wastes generated from metal finishing operations. Therefore, the Agency believes electrolytic oxidation, alkaline chlorination, wet air oxidation, high temperature cyanide hydrolysis, SO_2/air oxidation, incineration, and stabilization are applicable and demonstrated to treat off-specification product, wastewater, and contaminated soil and sludge forms of the P codes listed.

Metals can be treated by chemical precipitation followed by filtration, sludge dewatering, and stabilization for wastewaters, and by stabilization for nonwastewaters.

8.3 Identification of Best Demonstrated Available Technology

EPA believes that these wastes are similar to F011 wastes generated from metal heat treating operations. These P-code wastes are soluble cyanide compounds or leak or spill residues containing these compounds. Therefore, the Agency believes that the best way to treat these P-code wastes is to dissolve them in water and then treat them by one of the demonstrated treatment technologies identified above. Upon dissolution, these P-code wastes liberate free cyanide and not metal-cyanide complexes. These discarded commercial chemical products do not contain significant concentrations of iron, and therefore the Agency believes that the treatment standards need not reflect the difficulties of treating complexed cyanides.

Of the demonstrated technologies identified in Section 8.2, the "best" technology for cyanide treatment for wastewaters for the P-code cyanide wastes is alkaline chlorination. For treatment of BDAT metal constituents for these wastes where regulated, the "best" technology is chemical precipitation followed by filtration for wastewaters and stabilization for nonwastewaters. Cyanide standards for nonwastewater residuals are based on generation of treatment sludges by a treatment system consisting of electrolytic oxidation followed by alkaline chlorination, chemical precipitation, and sludge dewatering.

Determination of "best" technology and "availability" for both cyanides and metals follows the rationale that was presented in Section 5.2 for the waste codes F011 and F012, generated from metal heat treating operations, because these wastes are most similar to the P-code cyanide wastes.

8.4 Selection of Regulated Constituents

EPA is promulgating treatment standards for total and amenable cyanide in both wastewaters and nonwastewaters for all of the P-code wastes listed in Table 8-1. The BDAT list metals proposed for regulation, also listed in Table 8-1, are nickel for P074 and silver for P099 and P104. Silver standards for P099 and P104 for wastewaters and barium standards for P013 wastewaters and nonwastewaters have not been promulgated because the Agency has no treatment performance data for these metals.

The Agency had proposed copper and zinc as regulated constituents only for the copper cyanide (P029) and zinc cyanide (P121) wastes. The Agency is not promulgating treatment standards for copper and zinc. For the P029 and P121 waste codes, copper and zinc, as the primary metal constituents, may be present in very high concentrations (up to 55 percent in the pure compound wastes). EPA has determined that these wastes are aquatic toxins and considered adding them to Appendix VIII for that reason. The Agency does not, however, consider these metals to be as hazardous in a land disposal environment as they are in an aquatic environment and has not included them on Appendix VIII. Thus, standards for copper and zinc have not been promulgated for P029 and P121, respectively.

8.5 Promulgated Treatment Standards

Treatment standards for cyanide in the P-code wastes listed in Table 8-1 are based on electrolytic oxidation followed by alkaline chlorination for the nonwastewaters and on alkaline chlorination for the wastewaters. Treatment standards for these wastes were transferred from the performance of the BDAT for the F011 and F012 waste codes generated from metal heat treating operations. These discarded commercial chemical products do not contain high concentrations of iron, and therefore the Agency believes that the treatment standards need not reflect difficulties of treating complex cyanides. The Agency is thus promulgating these concentration-based treatment standards because of the similarity of these P-code wastes to the listed metal heat treating wastes.

Treatment standards for nickel in P074 and silver in P099 and P104 nonwastewaters are based on the performance of stabilization of F006 nonwastewaters. Treatment standards for nickel in P074 wastewaters are based on the performance of chemical precipitation and filtration of K062 wastewaters. The Agency believes that these wastes are more difficult to treat than the corresponding P wastes based on the higher concentrations of metals and dissolved solids anticipated to be present in F006 and K062 as compared to the P wastes (i.e., up to 100,000 ppm).

All wastewater and nonwastewater residuals from treatment of these wastes must meet the wastewater and nonwastewater standards presented in Table 8-2 for the constituents listed in Table 8-1.

Table 8-1 P Waste Codes Proposed for Regulation

Waste code	Chemical compound	Regulated constituents
P013	Barium cyanide	Cyanide
P021	Calcium cyanide	Cyanide
P029	Copper cyanide	Cyanide
P030	Cyanides (soluble cyanide salts), N.O.S.	Cyanide
P063	Hydrocyanic acid, hydrogen cyanide	Cyanide
P074	Nickel cyanide	Nickel, cyanide
P098	Potassium cyanide	Cyanide
P099	Potassium silver cyanide	Silver, cyanide
P104	Silver cyanide	Silver, cyanide
P106	Sodium cyanide	Cyanide
P121	Zinc cyanide	Cyanide

Table 8-2 Proposed Treatment Standards for P-Code Cyanide Wastes

Constituent	Wastewater	Nonwastewater	
	Total composition (mg/l)	Total composition (mg/kg)	TCLP (mg/l)
Cyanide (amenable)	0.10	9.1	NA
Cyanide (total)	1.9	110	NA
Nickel (P074 only)	0.44	NA	0.32
Silver (P099 and P104 only)	NS	NA	0.072

NA = Not applicable.
NS = No treatment standard.

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APPENDIX A

ANALYTICAL METHODS AND QA/QC

This appendix presents analytical methods and the matrix spike recovery data for the treated waste samples from testing of F007. F011. and F012 wastes.

Table A-1. Analytical Methods - Plant A

Analytical method	Method number	Reference
Cyanides (total and amenable)	9012	1

1. USEPA. 1986. U.S. Environmental Protection Agency, Office of Solid Waste. Test methods for evaluating solid waste. 3rd ed. Washington, D.C.: U.S. Environmental Protection Agency.

[illegible]

Table A.2. Specific Procedures or Equipment Used for Analysis [illegible] When Alternatives or Equivalents Are Allowed in SW-846 Methods [illegible]

Analysis	SW-846 method	Sample aliquot	Alternative or equivalent allowed by SW-846 methods	Specific procedure used
Total and amenable cyanide	9010	500 ml	Hydrogen sulfide treatment may be required	Hydrogen sulfide treatment was not required
			A Fisher-Mulligan absorber or equivalent should be used	A Wheaton Distilling Apparatus absorber was used

Table A-3 Matrix Spike Recoveries for Cyanide - Plant A

Constituent	Original amount detected (µg/l)	Amount spiked (µg/l)	Spike		Duplicate spike		Relative percent difference[b]
			Amount recovered (µg/l)	Percent recovery[a]	Amount recovered (µg/l)	Percent recovery[a]	
Sample WGS4-101							
Cyanide, chlorinated	114,000	160,000	279,000	103	274,000	100	1.8
Cyanide, total	103,000	160,000	243,000	88	252,000	93	3.6
Sample WGS8-101							
Cyanide, chlorinated	<10	200	140	70	120	60	15
Cyanide, total	<10	200	<10	0.0[c]	<10	0.0[c]	NC
Sample WGS5-101							
Cyanide, chlorinated[d]	79.5	71.1	110	43	-	-	-
Cyanide, total[d]	99.4	69.3	170	102	173[e]	108	1.0
Cyanide, TCLP	854	1000	1820	97	1990	114	8.9
Sample WGS9-101							
Cyanide, chlorinated[d]	29.1	30.7	59.5	99	-	-	-
Cyanide, total[d]	34.7	7.99	42.1	93	44.0[f]	116	23
Cyanide, TCLP	40.8	200	225	92	222	91	1.3

NC = Not calculable.

- = No analysis performed.

[a] Percent recovery = 100 $(C_1 - C_o) / C_t$, where C_i is the amount recovered, C_o is the original amount detected.

[b] Relative percent difference = $| 100 (D_1 - D_2) / [(D_1 + D_2) / 2] |$, where D_1 and D_2 are the percent recoveries of the spike and duplicate spike.

[c] Zero percent recovery is attributed to matrix interference.

[d] Units for solids sample concentrations are mg/kg.

[e] Amount spiked for the matrix duplicate spike was 68.1 mg/kg.

[f] Amount spiked for matrix spike duplicate was 7.96 mg/kg.

Table A-4. Analytical Methods - Plant [illegible]

Analytical method	Method number	Reference
Cyanides (total and amenable)	9010	1

1. USEPA. 1986. U.S. Environmental Protection Agency, Office of Solid Waste. Test method for evaluating solid waste. 3rd ed. Washington, D.C.: U.S. Environmental Protection Agency.

[illegible]

Table A-5. Specific Procedures or Equipment Used for Analysis of Cyanide When Alternatives or Equivalents Are Allowed in SW-846 Methods [illegible]

Analysis	Method	Alternative or equivalent allowed	Specific equipment or procedure used
Cyanide	9010	Pretreatment with bismuth nitrate may be necessary if sulfides are present	Pretreatment was not required.
		Pretreatment with sulfamic acid may be necessary if nitrites/nitrates are present	Pretreatment was not necessary.
		A Fisher-Mulligan absorber or equivalent should be used	An ACE smog bubbler absorber was used
		A spectrophotometer suitable for measurements at 578 nm with a 1.0-cm cell or larger is required	A Bausch and Lomb Model Spectronic 21 was used

Table A 6 Matrix Spike/Matrix Spike Duplicate Results for Cyanide Plant B

Sample number	Sample conc. (µg/l)	Spike added (µg/l)	Spike result (µg/l)	% Recovery	Spike duplicate result (µg/l)	% Recovery	RPD
OL-03	16.11	24.75	29.16	52.7	28.97	52.0	0.7

OL-03 = Treated waste sample; Sample Set No 3

$$\text{RPD} = 100\,(\text{spike result} - \text{spike duplicate result})/\left(\frac{\text{spike result} + \text{spike duplicate result}}{2}\right)$$

Table A-7 Analytical Methods - Plant C

Treated waste	Analytical method	Method number	Reference
Treated nonwastewater	Cyanides (total and amenable)	9012	1
	Metals (EP toxicity)	1310	1
Treated wastewater	Cyanides (total and amenable)	9012	1

1. USEPA. 1986. U.S. Environmental Protection Agency, Office of Solid Waste. Test method for evaluating solid waste. 3rd ed. Washington, D.C.: U.S. Environmental Protection Agency.

Table A-8 Matrix Spike/Matrix Spike Duplicate Results for Total Cyanide Untreated F006 Nonwastewater

Sample result (ppm)	Spike added (ug)	Spike result (ug)	Percent recovery	Spike duplicate result (ug)	Percent recovery
120	30	144.0	80	139.0	63
47	30	75.8	96	71.3	81
13	30	27.4	48	37.6	82
3.7	30	33.7	100	32.5	96
0.40	30	26.2	86	29.2	96
53	30	81.2	94	77.6	82
270	30	298.0	93	299.0	97
270	30	304.0	113	305.0	116
160	30	187.6	92	192.7	109
230	30	261.8	106	264.5	115
410	30	433.7	79	437.3	91

Percent recovery = [(spike result-original amount)/spike added] x 100.

Table A.9 Matrix Spike Results for Total Cyanide in Aqueous Effluent - Plant C

Spike amount (ppm)	Spike recovery (ppm)	Percent recovery
2.0	1.88	94
2.0	1.94	97
2.0	1.93	96.5
2.0	1.9	95
2.0	1.9	95

APPENDIX B

SUMMARY OF WASTE COMPOSITION DATA

Table B 1 F006 Waste Composition Data

Constituent/ parameter (units)	Concentration (source) (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)^a	(8)^a
No. of data points with cyanide	11	2	6		12		100	6	6
BDAT Inorganics Other Than Metals (mg/kg)									
169. Cyanide (total)	<0.1-506	84.1-226	<2	-	0.1-5.8	-	<0.025-1,970	554-859	1,800-2,860
169. Cyanide (amenable)	<0.10-0.22	<1-153	<2	-	0.1	-	0.003-162		
170. Fluoride	-	-	-	268					
BDAT Metals (mg/kg)									
154. Antimony	-	-	<10	22.4	-	-		221-339	<6.2
155. Arsenic	-	-	2-5	<0.4	<6.24	-	-	0.353-0.797	0.48-0.76
156. Barium	0.74-85.5	-	20-45	28.8	9-57	-	-	35.8-54.0	6.39-7.92
157. Beryllium	-	-	<2	<0.1	<97.6	-		<0.19	<0.05
158. Cadmium	1.3-720	1,280-4,070	10-20	0.37-1.75	<11-1,320	ND-22,000	0.003-1,180	1.63-1.97	35,500-42,900
159. Total chromium	2-49,000	147-8,610	3,200-75,000	1,650-2,625	35-730	200-137,000	<0.002-290,000	622-803	4,290-5,380
160. Copper	1.4-27,400	345-28,100	90-775	1.87-135	<6-760	-	-	10,200-13,600	7,100-8,700
161. Lead	1.69-24,500	-	85-134	184-305	<6-408	-	<0.001-13,900	9.4-11.3	<6.92-9.7
162. Mercury	-	-	<1	<0.2	<0.32	-	-	<0.144-0.616	<0.137
163. Nickel	234-23,700	1,330-26,000	7,300-49,000	11.8-17	-	-	0.06-170,000	1,170-1,470	10,300-12,500
164. Selenium			<10		<19-<23	-		114-167	<0.16
165. Silver	0.51-38.9	-	<2	<0.6-<1.0	-	-	-	<1.26-1.99	<0.86
166. Thallium	-	-	<10	<20	-	-	-	<6.0	<12.7
167. Vanadium	-	-	-	1.26	-	-	-	1.75-2.5	3.66-4.44
168. Zinc	8.86-90,200	611-41,200	68-3,700	2,510-3,687	<29-220	-	-	9,130-12,700	4,160-5,320
221. Hexavalent chromium	-	-	0.14-1.0	-	0.25-25.4	-	<0.001-910		

Table B-1 (continued)

Constituent/ parameter (units)	Concentration (source) (9)
No. of data points with cyanide	13
BDAT Inorganics Other Than Metals (mg/kg)	
169. Cyanide (total)	3.7-560
169. Cyanide (amenable)	<.025-6.2
170. Fluoride	-
BDAT Metals (mg/kg)	
154. Antimony	-
155. Arsenic	-
156. Barium	-
157. Beryllium	-
158. Cadmium	-
159. Total chromium	-
160. Copper	-
161. Lead	-
162. Mercury	-
163. Nickel	-
164. Selenium	
165. Silver	-
166. Thallium	-
167. Vanadium	-
168. Zinc	-
221. Hexavalent chromium	-
Other Parameters	
Oil and grease (mg/g)	-
Moisture (%)	-
SP gravity (g/ml)	-
Acidity as $CaCO_3$ (mg/l)	-
Sulfide (mg/kg)	-
Total organic carbon (mg/kg)	-

Table B 1 (continued)

Constituent/ parameter (units)	Concentration (source)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)[a]	(8)[a]
Other Parameters									
Iron (mg/kg)							40 55200		
Oil and grease (mg/g)	0.03-37.7	-	-	-	-				
Moisture (%)	29.1-91.2	-	47.4-48.94	-	-			69 1-76 3	
SP gravity (g/ml)			1.38-1.493	-	-				
Acidity as $CaCO_3$ (mg/l)			1,412						
Sulfide (mg/kg)				21					
Total organic carbon (mg/kg)			<5,800						

[a] Each column presents compositions of wastes generated by different generators.

- = Not analyzed.

ND = Not detected.

References:

(1) Chemical Waste Management 1987. (All data points are below the total cyanide standard.)
(2) MRI 1987. (All data points are below the total cyanide standard.)
(3) USEPA 1986. (All data points are below the total cyanide standard.)
(4) John Deere Company 1988.
(5) Environ 1985. (All data points are below the total cyanide standard.)
(6) USEPA 1980.
(7) Versar 1986. (97 out of 100 data points are below the total cyanide standard.)
(8) PEI 1988. (One out of 12 data points is below the total cyanide standard.)
(9) CyanoKEM 1989. (All data points are below the total cyanide standard.)

Table B-2 F007 Waste Composition Data

Constituent/parameter (units)	Concentration (source)				
	(1)	(2)	(3)	(4)	(5)
BDAT Inorganics Other Than Metals (mg/l)					
Cyanide (amenable)	CBI	-			
Cyanide (iron)[a]	CBI	-	170		
Cyanide (total)	CBI	4,000-67,000	41,000	2,000-15,000	20,000-[illegible]
Fluoride	CBI	-		-	
BDAT Metals (mg/l)					
Cadmium	CBI	-	-	-	1,500
Chromium (total)	CBI	-	-	-	
Chromium (hexavalent)	CBI	-	-	-	400
Copper	CBI	-	-	-	-
Nickel	CBI	-	-	-	7,000-8,000
Zinc	CBI	-	-	-	-
Non-BDAT Metals (mg/l)					
Calcium	CBI	-	-	-	-
Iron	CBI	-	-	-	-
Magnesium	CBI	-	-	-	-
Manganese	CBI	-	-	-	-
Sodium	CBI	-	-	-	-
BDAT Volatiles (mg/l)					
Methanol	CBI	-	-	-	-
Other Parameters					
Carbonate (mg/l)	CBI	-	-	-	-
Total solids (%)	CBI	-	-	-	-
Ash (%)	CBI	-	-	-	-
Total suspended solids (mg/l)	CBI	-	-	-	-
Suspended ash (mg/l)	CBI	-	-	-	-
Chemical oxygen demand (mg/l)	CBI	-	-	-	-
pH	CBI	-	-	-	-
Specific gravity	CBI	-	-	-	-

[a] Cyanide (iron) is interpreted as a measurement of cyanide not amenable to chlorination.

- = Not analyzed.

Table B-2 (continued)

Constituent/parameter (units)	Concentration (source)					
	(6)	(6)	(6)	(6)	(7)	[illegible]
BDAT Inorganics Other Than Metals (mg/l)						
Cyanide (amenable)	64,200	5,700	25,600	28,200		
Cyanide (iron)[a]	-	-	-			
Cyanide (total)	66,900	8,010	27,600	30,200	41,900	[illegible]
Fluoride	-	-	-	-		
BDAT Metals (mg/l)						
Cadmium	16,300	-	10,600	-	1,350	
Chromium (total)	-	-	-	-	100	780
Chromium (hexavalent)						
Copper	-	2,880	383	-	19,510	440
Nickel	-	-	-	-	2,683	1,740
Zinc	-	-	-	15,700	4,708	<100
Non-BDAT Metals (mg/l)						
Calcium	-	-	-	-	-	-
Iron	-	-	-	-	498	470
Magnesium	-	-	-	-	-	-
Manganese	-	-	-	-	-	-
Sodium	-	-		-	-	-
BDAT Volatiles (mg/l)						
1,1-Dichloroethane	<0.002	<0.010	348	<0.002	-	-
Methanol	-	-		-	-	-
Methylene chloride	<0.002	0.0262	0.0324	<0.002	-	-
Toluene	<0.002	0.0562	0.0023	0.0137	-	-
1,1,1-Trichloroethane	<0.002	<0.010	0.011	<0.002	-	-
Other Parameters						
Carbonate (mg/l)	-	-		-	-	-
Total solids (%)	-	-		-	-	-
Ash (%)	-	-		-	-	-
Total suspended solids (mg/l)	-	-		-	-	-
Suspended ash (mg/l)	-	-		-	-	-
Chemical oxygen demand (mg/l)	-	-		-	-	-
pH	-	-		-	11.5	-
Specific gravity	-	-		-	-	-

[a] Cyanide (iron) is interpreted as a measurement of cyanide not amenable to chlorination.

- = Not analyzed.

References:

(1) USEPA 1988f.	(5) CyanoKEM 1987.
(2) Patterson and Minear 1973.	(6) MRI 1987.
(3) Versar 1986.	(7) CyanoKEM 1989.
(4) USEPA 1980.	(8) CyanoKEM 1987.

Table B-3 F008 Waste Composition Data

Constituent/parameter (units)	Concentration (source)				
	(1)	(2)	(2)	(2)	
BDAT Inorganics Other Than Metals (mg/kg)					
Cyanide (amenable)	-	11,700	21,700	34,200	
Cyanide (total)	64	11,900	26,600	34,300	50,000-55,000
BDAT Metals (mg/kg)					
Cadmium	-	-	13,000	-	<100
Chromium (hexavalent)	-	-	-	-	300
Copper	-	-	-	21,600	-
Lead	-	-	-	-	150-200
Nickel	-	-	-	-	300
Zinc	-	13,100	-	-	-
BDAT Volatiles (mg/kg)					
Methylene chloride	-	<1.20	<0.008	14.4	-

- = Not analyzed.

References:
(1) USEPA 1980.
(2) MRI 1987.
(3) CyanoKEM 1987.

Table B-4 F009 Waste Composition Data

Constituent/parameter (units)	Concentration (source)					
	(1)	(2)	(2)	(3)	4	
BDAT Inorganics Other Than Metals (mg/l)						
Cyanide (amenable)	-	52,000-90,000	-	-	62,300	
Cyanide (iron)[a]	-	-	100			
Cyanide (total)	350,000	-	40,000	4,000-8,000	64,600	5,200
BDAT Metals (mg/l)						
Cadmium	-	-	-	-	-	
Chromium (total)	-	-	-	-	-	<100
Chromium (hexavalent)	-	-	-	-	-	-
Copper	-	19,000	-	-	-	1,500
Lead	-	-	-	-	-	-
Nickel	-	5,100-5,500	-	-	7,310	-
Zinc	-	-	-	-	-	580
Non-BDAT Metals (mg/l)						
Iron	-	720-15,000	-	-	-	490

- = Not analyzed.

[a] Cyanide (iron) is interpreted as a measurement of cyanide not amenable to chlorination.

References:

(1) USEPA 1980.

(2) Versar 1986.

(3) Patterson and Minear 1973.

(4) MRI 1987.

(5) CyanoKEM 1987.

Table B-4 (continued)

Constituent/parameter (units)	Concentration (source)					
	(4)	(4)	(4)	(5)	(5)	[illegible]
BDAT Inorganics Other Than Metals (mg/l)						
Cyanide (amenable)	109,000	14,400	47,400	-		
Cyanide (iron)[a]	-	-	-	-		
Cyanide (total)	115,000	14,500	52,500	27,200	40,000-45,000	30,000
BDAT Metals (mg/l)						
Cadmium	388	-	-	-	200	-
Chromium (hexavalent)	-	-	-	-	<100	-
Copper		6,990	-	270	-	-
Lead	-	-	-	-	200	-
Nickel	-	-	7,510	1,050	12,000-15,000	-
Zinc	-	-	-	3,070	-	19,250
Non-BDAT Metals (mg/l)						
Iron	-	-	-	3,320	-	-

- = Not analyzed.

[a] Cyanide (iron) is interpreted as a measurement of cyanide not amenable to chlorination.

[b] A mixture of F009 (zinc plating waste) and a waste hypothlorite solution.

References:

(1) USEPA 1980.
(2) Versar 1986.
(3) Patterson and Minear 1973.
(4) MRI 1987.
(5) CyanoKEM 1987.

Table B-5 F010 Waste Composition Data

Constituent/parameter (units)	Concentration (source) (1)	 (2)
BDAT Inorganics Other Than Metals (mg/kg)		
Cyanide (total)	8,530	22,000
Other Parameters		
Heat content (Btu/lb)	-	5,000
Water (%)	-	ND
Oil and grease	-	>5 [a]

- = Not analyzed.
ND = Not detected.

[a] Data submitted to the Agency did not report an oil and grease concentration. However, these waste composition data represent a waste that was incinerated, and CyanoKEM indicated that a waste must have oil and grease concentration of at least 5 percent in order to be incinerated.

References:
(1) USEPA 1980.
(2) CyanoKEM 1988.

Table B-6 F011 Waste Composition Data

Constituent/parameter (units)	Concentration (source)			
	(1)	(2)	(2)	(3)
BDAT Inorganics Other Than Metals (mg/l)				
Cyanide (amenable)	I	-	34,000-35,000	
Cyanide (total)	5,350[a]	10,000-12,000	-	85,000-90,000
Fluoride	5.55	-	-	
BDAT Metals (mg/l)				
Antimony	0.029	-	-	-
Barium	1.0	-	-	-
Cadmium	0.01	-	-	<100
Chromium (hexavalent)	<0.01	-	-	1,000-1,500
Chromium (total)	5.42	-	-	-
Copper	1.03	-	-	-
Lead	1.1	-	-	500-1,000
Nickel	2.88	-	-	300
Silver	0.0072	-	-	-
Vanadium	0.156	-	-	-
Zinc	0.338	-	-	-
Non-BDAT Metals (mg/l)				
Iron	27.8	-	-	-
Potassium	18,500	-	-	-
Sodium	32,200	-	-	-
Non-BDAT Inorganics Other Than Metals (mg/l)				
Carbonate	87,000	-	-	-
Chloride	21,300	-	-	-
Sulfate	90.5	-	-	-
Other Parameters				
Total solids (%)	19.7	-	-	-
Total suspended solids (%)	3.84	-	-	-
Chemical oxygen demand (mg/l)	7,140	-	-	-
Total organic carbon (mg/l)	19,500	-	-	-
Oil and grease (mg/l)	11.0	-	-	-

I = Analytical interference. Analysis of partially treated sample indicates that this value is <5120 mg/l.

- = Not analyzed.

[a] The concentration of total cyanide referred to here is based on testing of a waste that had been dissolved in aqueous solution for electrolytic treatment. The concentration of total cyanide in the solid waste treated was approximately 90,000 mg/kg, and the concentration of amenable cyanide was <2.5 mg/kg.

References:

(1) USEPA 1988e.

(2) Environ 1985.

(3) CyanoKEM 1987.

Table B-7 F012 Waste Composition Data

Constituent/parameter (units)	Concentration (source) (1)	(2)	(2)	(3)	(4)
BDAT Inorganics Other Than Metals (mg/kg)					
Cyanide (total)	21	26,800	8,400	1,500	60,000-[illegible]
Fluoride	6.5	-	-		
BDAT Metals (mg/kg)					
Barium	98	-	-	-	
Cadmium	5.31	-	-	-	<100
Chromium (hexavalent)	-	-	-		350
Chromium (total)	11	-	-	-	
Copper	307	-	-	-	
Lead	28	-	-	-	500-600
Nickel	758	-	-	-	400 500
Silver	0.73	-	-	-	-
Vanadium	6.7	-	-	-	-
Zinc	54	-	-	-	-
BDAT Volatile Organics (µg/kg)					
Acetone	250	-	-	-	-
Chloroform	110	-	-	-	-
Methylene chloride	11	-		-	-
Toluene	28	-		-	-
BDAT Semivolatile Organics (µg/kg)					
Bis(2-ethylhexyl) phthalate	1,600	-		-	-
PCBs (µg/kg)					
Aroclor 1254	35	-		-	-
Non-BDAT Metals (mg/kg)					
Iron	2,880	-		-	-
Sodium	1,276	-		-	-
Non-BDAT Inorganics Other Than Metals (mg/kg)					
Chloride	992	-		-	-
Sulfate	6,900	-		-	

Table B-7 (continued)

Constituent/parameter (units)	Concentration (source)				
	(1)	(2)	(2)	(3)	4
Other Parameters					
Total solids (%)	60.5	-	-		
Total organic carbon (mg/kg)	540	-	-	-	
Oil and grease (mg/kg)	432	-	-	-	
pH	-	-	-	10.5 11.0	

- = Not analyzed.

References:

(1) USEPA 1988e.

(2) USEPA 1980.

(3) Environ 1985.

(4) CyanoKEM 1987.

2745g

Table B-8 F006 Waste Characterization Data - Composite Samples

Constituent parameter	Concentration (units) Total untreated waste (mg/kg)	Concentration (units) Alkaline leachate untreated waste (mg/L)
Sample Set #1 (1/87)		
Cyanide (amenable)	-	1.0
Cyanide (total)	54	2.4
Sample Set #2 (2/87)		
Cyanide (amenable)	-	0.1
Cyanide (total)	320	0.41
Sample Set #3 (3/87)		
Cyanide (amenable)	-	0.28
Cyanide (total)	120	0.76
Sample Set #4 (4/87)		
Cyanide (amenable)	-	0.55
Cyanide (total)	47	0.55
Sample Set #5 (5/87)		
Cyanide (amenable)	-	<0.025
Cyanide (total)	13	0.64
Sample Set #6 (6/87)		
Cyanide (amenable)	-	0.11
Cyanide (total)	3.7	0.12
Sample Set #7 (7/87)		
Cyanide (amenable)	-	0.46
Cyanide (total)	240	0.5

Table B-8 (continued)

	Concentration (units)	
Constituent/parameter	Total untreated waste (mg/kg)	Alkaline leachate untreated waste (mg/L)
Sample Set #8 (8/87)		
Cyanide (amenable)	-	<0.025
Cyanide (total)	300	1.1
Sample Set #9 (9/87)		
Cyanide (amenable)	-	<0.025
Cyanide (total)	400	<0.025
Sample Set #10 (10/87)		
Cyanide (amenable)	-	6.2
Cyanide (total)	53	6.2
Sample Set #11 (11/87)		
Cyanide (amenable)	-	0.11
Cyanide (total)	270	0.46
Sample Set #12 (12/87)		
Cyanide (amenable)	-	0.09
Cyanide (total)	310	0.09
Sample Set #13 (1/88)		
Cyanide (amenable)	-	-
Cyanide (total)	160	0.095
Sample Set #14 (2/88)		
Cyanide (amenable)	-	<0.025
Cyanide (total)	230	0.42

Table B-8 (continued)

Constituent parameter	Concentration (units) Total untreated waste (mg/kg)	Alkaline leachate untreated waste (mg/L)
Sample Set #15 (3/88)		
Cyanide (amenable)	-	0.4
Cyanide (total)	430	2.4
Sample Set #16 (4/88)		
Cyanide (amenable)	-	0.1
Cyanide (total)	410	0.1
Sample Set #17 (5/88)		
Cyanide (amenable)	-	0.26
Cyanide (total)	25	0.31
Sample Set #18 (6/88)		
Cyanide (amenable)	-	1.3
Cyanide (total)	560	1.3

Table B-9 F006 Waste Characterization Data Submitted by Plant F

Date of Sampling	Untreated F006 Waste			
	Total CN	Amenable CN	Leachate[a]	
			Total	Amenable
09/09/82	30.108	0.386	0.110	-
12/01/82	45.753	17.214	0.190	-
03/08/83	18.032	18.032	0.009	0.009
06/07/83	3.171	0.272	<0.002	<0.002
09/13/83	1.416	<0.002	<0.002	<0.002
12/19/83	14.985	2.430	<0.002	<0.002
03/22/84	10.469	9.747	<0.002	<0.002
06/26/84	0.249	<0.002	<0.002	<0.002
09/06/84	14.904	14.904	0.050	-
12/10/84	16.192	16.192	<0.002	<0.002
03/12/85	44.800	30.400	<0.002	<0.002
06/24/85	9.455	<0.002	<0.002	<0.002
09/04/85	40.500	23.400	<0.002	<0.002
12/03/85	2.753	0.741	<0.002	<0.002
03/05/86	7.484	0.151	0.080	<0.002
06/11/86	1.988	1.988	<0.002	<0.002
09/08/86	0.114	0.114	<0.002	<0.002
12/08/86	0.125	0.125	<0.002	<0.002
03/04/87	9.438	9.438	<0.002	<0.002
06/10/87	6.149	0.427	<0.0	<0.002
09/18/87	0.125	<0.002	<0.0	<0.002
12/02/87	0.189	<0.002	<0.0	<0.002
03/07/88	1.246	-	0.020	0.020
06/02/88	0.119	-	<0.002	-

[a] Distilled water leachate was used.

- = Not analyzed.

Reference: UTC Pratt & Whitney, 1989.

Table B-10 F006 Waste Characterization Data Submitted by Plant 6

Date of Sampling	Untreated F006 Waste Total CN	 Amenable CN	Leachate[a] Total	 Amenable
09/09/82	25.272	3.240	0.005	-
12/01/82	14.308	2.920	0.040	-
03/10/83	19.136	6.578	0.088	0.085
06/07/83	23.332	16.271	<0.002	-
09/13/83	27.307	4.606	<0.002	-
12/09/83	22.848	0.874	<0.002	<0.002
03/15/84	11.718	7.182	<0.002	<0.002
06/20/84	51.840	36.000	<0.002	<0.002
09/10/84	28.797	3.972	<0.002	<0.002
12/13/84	23.596	23.596	0.018	-
03/10/85	34.797	0.037	<0.002	<0.002
06/04/85	2.841	2.841	<0.002	<0.002
09/03/85	8.876	8.876	<0.002	<0.002
12/03/85	5.989	0.108	<0.002	<0.002
03/11/86	2.106	0.130	<0.002	<0.002
06/10/86	6.495	0.433	<0.002	<0.002
09/09/86	0.122	<0.002	<0.002	<0.002
12/16/86	3.302	0.034	0.036	0.036
03/17/87	0.249	<0.002	<0.002	<0.002
06/16/87	3.190	3.190	<0.002	<0.002
09/15/87	9.600	2.400	<0.002	<0.002
12/01/87	12.800	72.000	<0.002	<0.002
03/08/88	19.110	6.468	<0.002	-
06/07/88	<0.119	-	<0.002	-

[a] Distilled water leachate was used.

- = Not analyzed.

Reference: UTC Pratt & Whitney, 1989.

Table B-11 F006 Waste Composition Data Submitted by Waste Management, Inc

Sample number	Total cyanide concentration (ppm)	Sample number	Total cyanide concentration (ppm)	Sample number	Total cyanide concentration (ppm)
E1	0	E37	18	A6	0
E2	0	E38	149	A7	10
E3	0	E39	0	A8	0
E4	80	E40	0	A9	0
E5	702	E41	0	A10	0
E6	0	E42	0	A11	0
E7	0	E43	937	A12	0
E9	29	E44	28	A13	187
E10	6	E45	0	A14	0
E11	0	E46	71	A15	9
E12	2	E47	0	A16	9
E13	45	E48	373	A17	10
E14	2	E49	0	A18	56
E15	72	E50	0	A19	18
E16	0	E51	0	A20	185
E17	0	E52	80	A21	75
E18	0	E53	524	A22	331
E21	0	E54	0	A23	26
E22	0	E55	0	A24	0
E23	0	E56	0	A25	0
E24	19	E57	9	A26	0
E25	0	E58	0	A27	0
E26	184	E59	0	A28	0
E27	0	E60	27	A29	335
E29	173	E61	18	A30	0
E30	318	A1	0	A31	739
E32	0	A2	9	A32	71
E33	214	A3	0	A33	45
E34	68	A4	0	A34	0
E35	18	A5	0	A35	0
E36	64				

Data are from a survey conducted by Chemical Waste Management, Inc., a subsidiary of Waste Management, Inc. in 1987 at two Waste Management, Inc. sites. Data on the treatment applied (if any) prior to sampling was not submitted to EPA.

Reference: Waste Management, Inc. 1989

Table B-12 F006 Waste Composition from 1986 National Survey of Hazardous Waste Generators

EPA ID No	Waste code(s)	Total cyanide concentration (ppm)
NCD 065 300 579	F006	0
NCD 065 300 579	F006	DK
NCD 065 300 579	F006	DK
NCD 041 466 257	F006/F007/F008/F009	71
NCD 041 466 257	F006	71
WID 006 090 187	F006	<1
WID 006 090 187	F006/F008	DK
WAD 097 824 460	F006/D002/D008	0
TND 034 818 732	F006	0
TND 980 559 702	F006/F007	0
TND 980 559 702	F007	0
TXD 041 128 083	F006	0
PAD 003 050 846	F006	NA
PAD 003 050 846	F006/D002	DK
PAD 003 050 846	F006	0
NCD 067 441 394	F006	NA
NCD 003 229 358	F006	DK
OHD 004 469 375	F006	0.9
OHD 005 052 493	F006	16
ORD 065 436 180	F006	0.05
ORD 080 725 592	F006	0
PAD 000 800 680	F006/D006/D007	10
PAD 001 127 331	F006	2
WID 006 096 192	F006	95
MID 006 409 387	F006	0
MID 006 407 597	F006/F019	0.141
MID 006 024 699	F006	DK
MAD 001 034 016	F006	500
KSD 006 325 013	F006	33
KYD 006 382 717	F006	DK
MAD 001 014 026	F006	0
KYD 990 876 252	F006	55,400
GAD 008 966 400	F006	10,000
IND 006 066 377	F006	DK
	F006	P

Table B-12 (continued)

EPA ID No	Waste code(s)	Total cyanide concentration (ppm)
AZT 050 010 636	F006	0
AZD 098 046 857	F006	0
ALD 078 960 234	F006	DK
CAD 009 158 932	F006	0
CAD 047 784 871	F006	0
PRD 090 519 752	F006	0
NYD 002 113 975	F006	0
NYD 002 204 543	F006/D006/D007/D008	1
NYD 002 204 543	F006/D003	<1.000
OKD 053 958 765	F006	≤30.000
MID 072 583 750	F006	0.066
MID 009 305 665	F006/D002/D007	5
MID 009 305 665	F006	1
MID 009 305 665	F006	0.03
IND 006 421 143	F006/F008/F009	0.03
PRD 090 592 544	F006	10.000
PRD 090 592 544	F006	350
NCD 067 203 752	F006/F007	DK
NCD 067 203 752	F006	233
PRD 980 650 709	F006	0
PAD 002 327 708	F006	0
PAD 002 346 088	F006/F008	1
PAD 003 346 088	F006/F008	P
PAD 003 006 798	F006	P
IND 067 879 106	F006	1
IND 067 879 106	F006	5
IND 006 932 305	F006	5
IND 006 932 305	F006	1
AZD 009 000 050	F006	DK
IAT 200 011 187	F006	1
FLD 004 117 077	F006/D008	0
NHD 001 079 045	F006	P
NHD 001 091 073	F006/D006/D007/D008	NA
NYD 010 783 967	F006	P
NYD 002 217 834	F006/F008	1
NYD 002 217 834	F006	0
NYD 000 813 394	F006	DK
PAD 058 445 313	F006	17
PAD 058 445 313	F006	0
PAD 990 752 099	F006/F008/F009/D008	24
PAD 390 752 099	F006/F006	3.555
PAD 990 752 099	F006/F009/D002	<1.000
PRD 090 383 860	F006	0
PRD 991 291 857	F006	1
MID 005 477 773	F006	0
		<0.1

Table B-12 (continued)

EPA ID No.	Waste code(s)	Total cyanide concentration (ppm)
MID 005 477 773	F006	<0.1
MID 005 477 773	F006	<0.1
MAD 071 705 222	F006	0
PAD 003 024 205	F006	<1
OKD 094 029 063	F006	100
RID 000 791 061	F006	0.11
TND 003 374 685	F006/F019/P030	32
TND 003 381 225	F006	0
VAD 098 444 813	F006	0
VAD 980 715 670	F006	0
PAD 015 139 470	F006	<0.1
PAD 051 397 700	F006	DK
TND 003 381 894	F006	118
TND 007 028 442	F006	0
TXD 058 212 671	F006/F008	0
NCD 041 463 761	F006	NA
OKD 070 038 823	F006	1
CTD 001 165 695	F006	P
ILD 005 137 914	F006	10
ILD 005 098 694	F006/D006	10
IAD 065 205 056	F006/F007	9
CTD 001 181 932	F006/F007	15
CTD 001 181 932	F006	0
FLD 083 200 998	F006	1
FLD 083 200 998	F006	1
FLD 067 242 164	F006	0
DED 002 369 205	F006	DK
CTD 001 166 453	F006/F007	DK
MID 005 379 888	F006	NA
FLD 095 558 466	F006	0.05
TND 173 440 124	F006	0.1
IAD 047 303 771	F006	DK
IAD 047 303 771	F006	DK
IAD 047 303 771	F006	300
ILD 005 215 421	F006	0
RID 001 201 508	F006	0
RID 001 201 508	F006	0
KYD 079 674 016	F006	0
SOD 067 012 070	F006	NA
KYD 005 383 385	F006/F008	0.26
MDD 003 070 349	F006	0
CAD 096 014 162	F006	NA
CAD 096 014 162	F006	NA
CAD 096 014 161	F006	NA
CTD 001 167 519	F006	0

Table B-12 (continued)

EPA ID No	Waste code(s)	Total cyanide concentration (ppm)
GAD 980 842 975	F006	0
ILD 002 472 360	F006	0
KSD 065 755 100	F006	NA
TND 095 671 071	F006	NA
MID 093 824 415	F006	4.25
MID 093 824 415	F006	2.4
MID 093 824 415	F006	0.23
MAD 001 014 174	F006	13
MOD 043 935 048	F006/F002/D006/D007	0
MOD 006 264 881	F006	0
RID 000 791 434	F006	0
ALD 980 559 843	F006	0.0003
CAD 008 296 055	F006	NA
WID 000 820 001	F006	NA
ORD 980 833 891	F006	0
KYD 094 203 213	F006	0
NCD 000 320 575	F006	18
COD 058 158 775	F006	3
OHD 065 986 200	F006	1
MSD 050 243 534	F006	0
AZD 055 646 921	F006	DK
TND 041 150 012	F006	0
AZT 000 624 443	F006/F002/D007	0
AZT 000 642 443	F006	0
IAD 000 805 143	F006	0
OHD 005 043 443	F006	130
UTD 009 073 214	F006	0
OHD 004 282 703	F006	<1
KYD 098 950 306	F006	6
COD 082 657 420	F006	0
NCD 042 269 134	F006	DK
MOD 991 293 564	F006	1
MOD 991 293 564	F006	<1
MOD 991 293 564	F006	0
MOD 991 293 564	F006	0
PAD 002 334 142	F006	0
PAD 002 334 142	F006	0
ARD 000 604 956	F006	DK
ALD 000 608 216	F006/D007	1
VAD 003 142 510	F006	21
MND 004 370 693	F006/D006/D007/D008	<10
CTD 001 182 815	F006	ND
CTD 065 521 304	F006	0
CTD 065 521 304	F006	0
FLD 001 926 161	F006	0

Table B-12 (continued)

EPA ID No	Waste code(s)	Total cyanide concentration (ppm)
MAD 001 010 826	F006	0
WID 980 792 196	F006	126
GAD 003 306 750	F006	1
GAD 003 306 750	F006	1
AZD 074 440 470	F006	0
KYD 046 659 603	F006	2
VTD 002 068 484	F006	NA
TXD 981 913 668	F006	DK
TXD 981 913 668	F006	4
CTD 001 181 728	F006/F007	250
CAD 008 492 951	F006	0
ADL 008 214 090	F006	3
MIT 270 019 698	F006	0.09
MID 006 014 104	F006	DK
MOD 007 174 485	F006	0.3
MOD 000 822 668	F006	DK
MOD 000 822 668	F006	DK
MND 980 700 900	F006	DK
MID 980 700 876	F006	0
MID 980 700 876	F006	DK
MID 005 356 784	F006	12
MID 005 356 688	F006	DK
MAD 001 138 726	F006	126
KYD 006 386 056	F006	160
KYD 057 591 133	F006	18
NCD 003 951 878	F006	120
OHD 052 151 701	F006	7.61
OHD 980 711 825	F006	DK
CAD 990 843 989	F006	DK
CAD 990 843 989	F006	DK
CAD 990 843 989	F006	DK
LAD 070 471 875	F006	0
MAD 000 844 571	F006	DK
MOD 980 859 607	F006	DK
GAD 003 480 530	F006/D002	350
GAD 003 480 530	F006/D007	0
GAD 003 480 530	F006/D007	<0.05
FLD 050 455 278	F006	NA
ARD 035 500 818	F006	1
ARD 035 500 818	F006	9
AZT 000 623 702	F006	0
CAD 008 344 285	F006	NA
CAD 008 488 025	F006	0
CAD 009 125 535	F006/F008	P
CAD 046 589 305	F006	

Table B-12 (continued)

EPA ID No.	Waste code(s)	Total cyanide concentration (ppm)
CAD 076 306 836	F006	DK
CTD 000 791 095	F006	0
CTD 000 842 492	F006	131
CTD 000 844 332	F006	15
CTD 001 149 459	F006	20
CTD 001 149 459	F006	10
CTD 001 149 459	F006	40
CTD 001 149 459	F006	40
CTD 001 168 137	F006	625
CTD 001 179 316	F006	DK
CTD 001 183 078	F006	0
CTD 001 449 511	F006	0
CTD 001 449 784	F006	DK
CTD 001 453 216	F006	DK
CTD 002 496 909	F006	15
CTD 058 865 072	F006	0
CTD 080 848 666	F006	P
FLD 001 647 015	F006	0
FLD 001 647 015	F006/F007/F008	62
GAD 006 924 872	F006	DK
GAD 006 924 872	F006	1
GAD 075 920 801	F006	40
GAD 097 392 971	F006	11
ILD 000 608 471	F006	1
ILD 000 716 894	F006	.00
ILD 005 109 525	F006	DK
ILD 006 271 696	F006/F007	5
ILD 006 271 696	F006	NA
ILD 006 271 696	F006/F007	0
ILD 006 271 696	F006/F007/F008	5
ILD 085 224 376	F006	1
IND 000 780 544	F006	0
IND 000 806 836	F006	8
IND 000 806 851	F006	0
IND 006 806 050	F006	0
IND 006 392 773	F006	DK
IND 016 584 641	F006	1
IND 052 959 640	F006	NA
IND 052 959 640	F006	0
IND 980 700 801	F006	1
KSD 007 145 899	F006	0
KYD 006 387 021	F006	DK
KYD 006 395 644	F006	DK
KYD 044 914 356	F006	5,000
LAD 001 809 896	F006	0

Table B-12 (continued)

EPA ID No	Waste code(s)	Total cyanide concentration (ppm)
LAD 067 033 944	F006	0
MAD 001 114 206	F006	NA
MAD 001 114 206	F006	0
MAD 001 114 206	F006	0
MAD 001 128 032	F006	1
MAD 001 128 032	F006	1
MAD 053 452 637	F006	0
MAD 046 279 311	F006	0
MID 005 069 257	F006	0
MID 005 356 860	F006	14
MID 005 356 867	F006	0
MID 005 422 514	F006	0
MID 055 850 127	F006	2
MID 081 601 122	F006	0
MID 081 601 122	F006	0
MID 081 601 122	F006	0
MID 081 601 122	F006	0
MID 098 011 992	F006	230
MID 098 011 992	F006	1
MID 980 795 512	F006/F008/P029	6.4
MIT 270 010 549	F006	0
MND 006 156 590	F006/F012	90
MSD 004 448 775	F006	P
NCD 003 154 010	F006	DK
NCD 003 154 010	F006	DK
MCD 041 463 761	F006	NA
NJD 002 202 885	F006	10
NJD 002 353 951	F006	76
NJD 006 980 924	F006	NA
NYD 001 325 661	F006	DK
OHD 000 724 153	F006	320
OHD 000 816 629	F006	0
OHD 004 288 288	F006	34
OHD 039 461 314	F006	0.3
OHD 055 522 429	F006	50
ORD 089 452 353	F006	0
PAD 001 643 691	F006	1
PAD 002 344 315	F006	698
PAD 002 344 315	F006	8
PAD 002 344 315	F006	DK
PAD 002 344 315	F006	1
PAD 005 569 538	F006	0
PAD 005 569 538	F006	0
PAD 015 139 470	F006	0.1
PAD 085 690 592	F006/F007/F008/F009/F010/F011	200

Table B-12 (continued)

EPA ID No.	Waste code(s)	Total cyanide concentration (ppm)
PAD 085 690 592	F006/F007/F008/F009/F010/F011	200
PAD 085 690 592	F006	200
PAD 085 690 592	F006/F007/F008/F009/F010	10
PAD 097 880 538	F006	1
SCD 069 326 171	F006	2
SCD 990 704 470	F006	DK
TND 042 205 971	F006	0
TND 042 205 971	F006/F007	100
TND 069 080 513	F006	5.000
TXD 030 171 379	F006	DK
TXD 055 318 273	F006	DK
TXD 058 212 671	F006/F008	0
TX 321 382 0738	F006	NA
TX 321 382 0738	F006	NA
WAD 041 337 130	F006	DK
WAD 041 337 130	F006	DK
WAD 048 440 424	F006	15
WID 980 704 209	F006	630
PAD 045 297 066	F006	P
CAD 000 628 149	F006	400
ALD 004 002 333	F006	0
ALD 078 960 234	F006	1
ALD 078 960 234	F006	1
ALD 078 960 234	F006	DK
AZD 055 646 921	F006	DK
AZD 074 440 470	F006	0
CAT 080 013 683	F006	0
COD 007 060 890	F006	0
COD 007 060 890	F006	450
COD 007 060 890	F006	0
COD 007 060 890	F006	0
COD 007 060 890	F006	0
COD 007 060 890	F006	0
COD 007 091 879	F006	0
COD 007 092 513	F006	DK
CTD 056 745 540	F006	0
IAD 005 269 527	F006	0.6
IAD 005 285 655	F006	5.0
IAD 006 537 237	F006	DK
ILD 000 670 828	F006	73
ILD 107 625 691	F006	0
IND 006 068 506	F006	DK
IND 006 419 964	F006	1
IND 067 879 106	F006	5
IND 081 523 284	F006	1

Table B-12 (continued)

EPA ID No.	Waste code(s)	Total cyanide concentration, ppm
KYD 006 379 [illegible]	F006	0
KYD 046 659 [illegible]	F006	2
MID 005 327 560	F006	DK
MID 005 327 560	F006	DK
MID 005 327 560	F006	DK
MID 005 327 560	F006	0
MID 006 021 414	F006	NA
MID 057 395 [illegible]	F006	4
MND 006 148 [illegible]	F006	0
MOD 007 120 652	F006	160
MSD 008 181 5[illegible]	F006/F007/F008/F009	5
NCD 000 615 672	F006	15
NCD 003 951 876	F006	120
NCD 041 230 416	F006	16
NCD 048 181 216	F006	10
NED 065 133 167	F006	DK
NHD 001 089 465	F006	0
NVD 085 286 037	F006	0
NYD 002 217 834	F006	0
NYD 006 015 560	F006	150
OHD 980 701 825	F006	DK
PAD 000 800 680	F006	10
PAD 002 346 086	F006/F008	DK
RID 001 191 055	F006	0
RID 001 191 055	F006	0
TND 003 381 225	F006	0
TND 980 559 702	F006	0
TND 980 559 702	F006	0
TXD 041 128 083	F006	0
TXD 980 867 352	F006	0
VAD 065 415 457	F006	0
TND 007 028 442	F006	0

DK = "Don't know." This has been interpreted by EPA to mean that it is not likely that these wastes contain cyanide above 590 mg/kg total concentration.

P = "Present-concentration unknown." This has been interpreted by EPA to mean that these wastes may contain cyanide above 590 mg/kg total concentration.

NA = Not analyzed. This has been interpreted by EPA to mean that it is not likely that these wastes contain cyanide above 590 mg/kg total concentration.

Table B-[illegible] F006 Waste Composition Data Submitted by National Association of Metal Finishers

Sample number	Sample label	Total cyanide (mg kg)	Reactive cyanide[a] (mg kg)
80701	Wastewater treatment filter cake	12,200	<0.34
807111	Wastewater [illegible]	11,700	55
802076	Wastewater treatment filter cake	1,300	0.16
809057	Waste F006	1,179	23
810036	Plating filter	940	2
808217	Wastewater [illegible]	750	0.93
806122	Filter press [illegible]	680	0.4
807005	Waste filter cake	610	1.1
807079	Wastewater	550	0.7
806258	Wastewater sludge	370	0.5
807007	Waste sludge	330	0.8
806080	Wastewater treatment filter cake	260	2.4
806225	Wastewater filter cake	190	63
806162	F006 waste	150	0.6
809339	Plating filter	[illegible]	0.62
810306	Chrome hydroxide	[illegible]	0.44
807047	Sludge	[illegible]	0.4
806207	Wastewater treatment sludge	[illegible]	1.5
807070	Zinc hydroxide	[illegible]	0.3
807212	Wastewater treatment sludge	[illegible]	<0.5
811334	Wastewater treatment sludge	69	0.25
809485	Wastewater treatment sludge	52	0.78
812318	F006 sludge	49.4	4.1
807046	Wastewater filter cake	48	<0.4
806098	Sludge	[illegible]	<6.3
810387	F006 Sludge	[illegible]	<0.42
806254	Metal hydroxide	[illegible]	<0.4
808036	Plating sludge	[illegible]	0.4
812345	Wastewater sludge	[illegible]	<0.36
807020	Nickel sludge	[illegible]	0.5
810137	Lagoon sludge	[illegible]	<0.44
806135	Sludge	30	<0.6
807113	Wastewater treatment sludge	[illegible]	<0.4
810114	F006	[illegible]	0.37
808219	Electroplating	[illegible]	0.42
806223	Wastewater treatment sludge	[illegible]	<0.4
805231	Wastewater treatment	19	<0.3
811015	Filter cake	16	<0.56
807112	Copper hydroxide	12	<0.4
811153	F006	11.5	NA

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Table B-13 (continued)

Sample number	Sample label	Total cyanide (mg/kg)	Reactive cyanide[a] (mg/kg)
806236	Wastewater treatment filter cake	11	<0.62
809245	Wastewater treatment filter cake	5.8	NA
807196	Wastewater treatment sludge	4.4	NA
804068	Wastewater sludge	3.7	NA
806095	Filter cake	3.7	NA
806041	Wastewater treatment filter cake	2.8	NA
807064	Wastewater filter	1.3	NA
804110	Plating sludge	<1	NA
811021	F006	0.65	MA
810390	Wastewater treatment sludge	<0.32	NA
805205	Filter cake sludge	<0.2	NA
803019	Plating sludge	<0.16	NA

[a] Reactive cyanide refers to weakly complexed cyanides liberated at a pH of 2 or higher.

NA = Not analyzed.

Reference: National Association of Metal Finishers 1989.

82794g

APPENDIX C

ANALYTICAL METHOD FOR MEASUREMENT OF THERMAL CONDUCTIVITY

METHOD OF MEASUREMENTS FOR THERMAL CONDUCTIVITY

The comparative method of measuring thermal conductivity has been proposed as an ASTM test method under the name "Guarded, Comparative, Longitudinal Heat Flow Technique." A thermal heat flow circuit is used which is the analog of an electrical circuit with resistances in series. A reference material is chosen to have a thermal conductivity close to that estimated for the sample. Reference standards (also known as heat meters) having the same cross-sectional dimensions as the sample are placed above and below the sample. An upper heater, a lower heater, and a heat sink are added to the "stack" to complete the heat flow circuit. See Figure 1.

The temperature gradients (analogous to potential differences) along the stack are measured with type K (chromel/alumel) thermocouples placed at known separations. The thermocouples are placed into holes or grooves in the references and also in the sample whenever the sample is thick enough to accommodate them.

For molten samples, pastes, greases, and other materials that must be contained, the material is placed into a cell consisting of a top and bottom of Pyrex 7740 and a containment ring of marinite. The sample is 2 inches in diameter and 0.5 inch thick. Thermocouples are not placed into the sample, rather, the temperatures measured in the Pyrex are extrapolated to give the temperature at the top and bottom surfaces of the sample material. The Pyrex disks also serve as the thermal conductivity reference material.

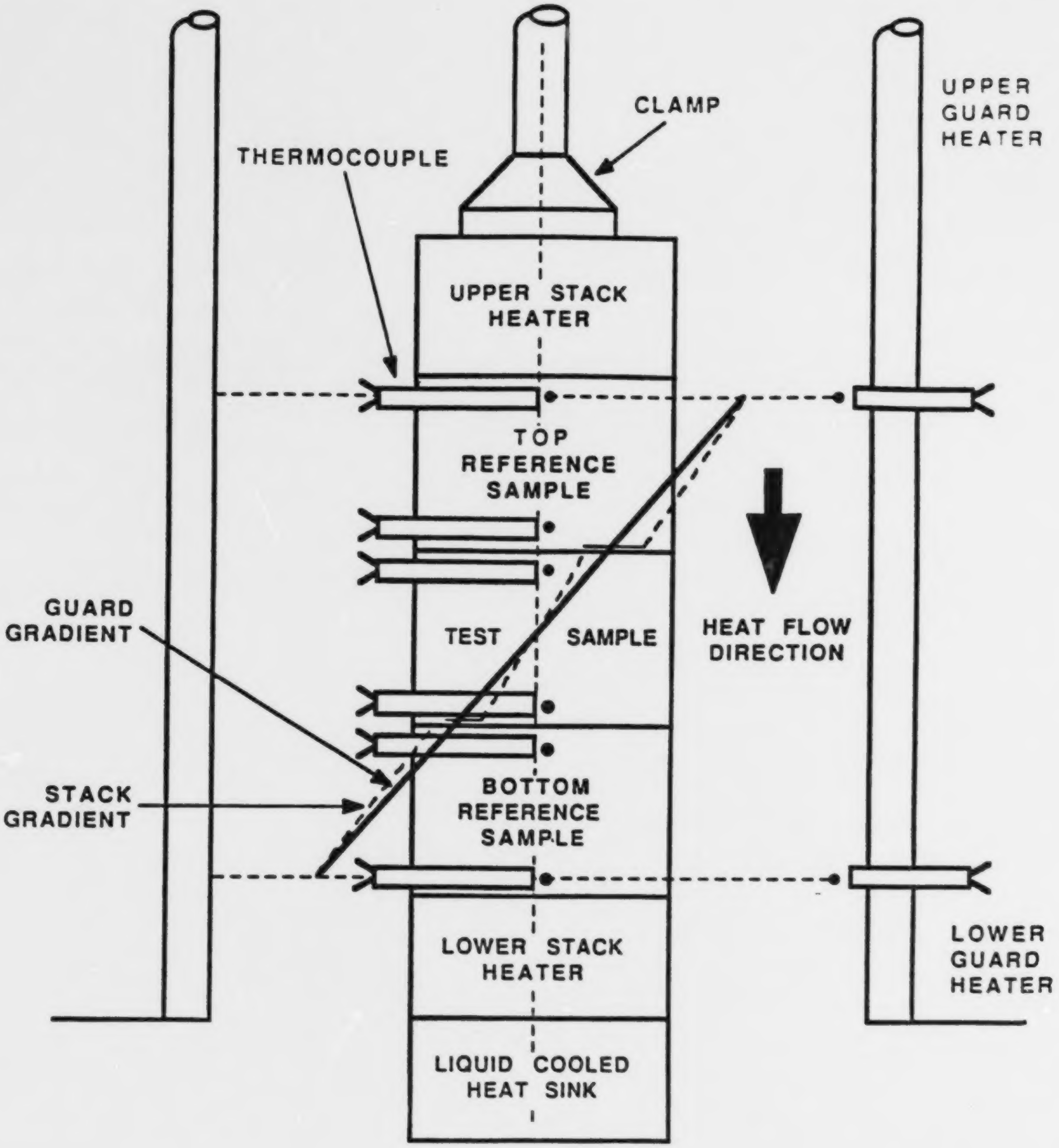
UPPER GUARD HEATER
CLAMP
THERMOCOUPLE
UPPER STACK HEATER
TOP REFERENCE SAMPLE
TEST SAMPLE
HEAT FLOW DIRECTION
GUARD GRADIENT
STACK GRADIENT
BOTTOM REFERENCE SAMPLE
LOWER STACK HEATER
LOWER GUARD HEATER
LIQUID COOLED HEAT SINK

FIGURE 1. SCHEMATIC DIAGRAM OF THE COMPARATIVE METHOD

The stack is clamped with a reproducible load to ensure intimate contact between the components. To produce a linear flow of heat down the stack and reduce the amount of heat that flows radially, a guard tube is placed around the stack and the intervening space is filled with insulating grains or powder. The temperature gradient in the guard is matched to that in the stack to further reduce radial heat flow.

The comparative method is a steady-state method of measuring thermal conductivity. When equilibrium is reached, the heat flux (analogous to current flow) down the stack can be determined from the references. The heat into the sample is given by

$$Qn_{in} = \lambda_{top}(dT/dx)_{top}$$

and the heat out of the sample is given by

$$Q_{out} = \lambda_{bottom}(dT/dx)_{botto}$$

where

λ = thermal conductivity

dT/dx = temperature gradient

and top refers to the upper reference while bottom refers to the lower reference. If the heat was confined to flow just down the stack, then Q_{in} and Q_{out} would be equal. If Q_{in} and Q_{out} are in reasonable agreement, the average heat flow is calculated from

$$Q = (Q_{in} + Q_{out})/2.$$

The sample thermal conductivity is then found from

$$\lambda_{sample} = Q/(dT/dx)_{sample}$$

The result for the K102 Activated Charcoal Waste tested here is given in Table 1. The sample was held at an average temperature of 42°C with a 53°C temperature drop across the sample for approximately 20 hours before the temperature profile became steady and the conductivity measured. At the conclusion of the test, it appeared that some "drying" of the sample had occurred.

Table 1 The Results of the Measurement of the Thermal Conductivity Using the Comparative Method

Sample	Temperature	Thermal conductivity
	(°C)	(W/mK)*
K101 waste	39	.273
K102 activated charcoal waste	42	.136

*1 W/mK = 6.933 Btu in/h ft^2 °F = .5778 Btu/h ft °F.